REPORT NO. GDC-BNZ 69-013-8
CONTRACT NAS 7-742

A study of

PRELAUNCH OPERATIONS FOR A SPACE STORABLE PROPELLANT MODULE

FINAL REPORT

GENERAL DYNAMICS
Convair Division

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Submitted to
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AND
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Prepared by
CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

FOREWORD

On 16 July 1969, contract NAS7-742 was issued to the Convair division of General Dynamics. On 22 October, an interim briefing was held at KSC. On 12 February 1970, the final briefing was presented at JPL. This final report is a comprehensive review of the entire scope of the study.

During the course of this contract, eight reports were issued:

GDC-BNZ69-013-1 through -6 were monthly status letters.

GDC-BNZ69-013-4 and -7 were viewgraph brochures from the interim and final briefings.

This final report is GDC-BNZ69-013-8.

Rocketdyne provided under P.O. No. 46-10094 propellant data and details on their test operations under NAS w-1229 and NAS 7-741.

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Due to the broad scope of prelaunch operations and the close interrelation between airborne and ground systems, many individuals were involved in this study. Particular contributions were made by:

James H. Kelley	JPL	Technical Manager
Jack Suddreth	NASA OART	Program Manager
Donald L. Young	JPL	Propulsion Module
Daniel A. Heald	Convair	Study Leader
Gordon R. Stone	Convair	Design
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Clifford Gurr	Martin-Marietta	Titan-Centaur-Viking
Maj. R. W. Smith	AFRPL	Meteorologist
Wayne Thomas	NASA LeRC	FLOX-Methane-Module

Additional individuals contacted by phone and attendees at the interim and final briefings are listed in Appendix C.

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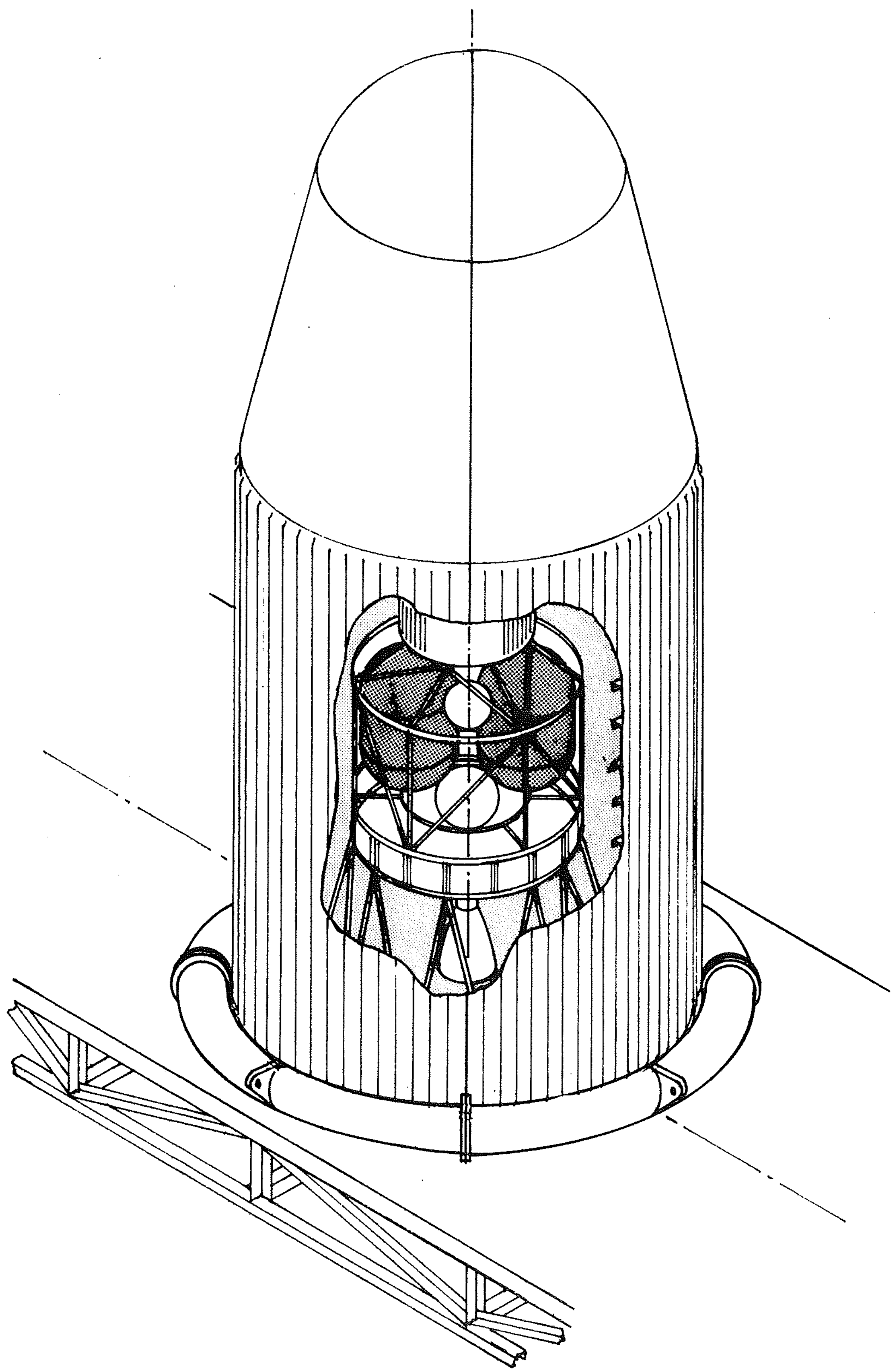


Encapsulated Space Storable Propulsion Module

SUMMARY

Under the guidance of JPL and using inputs from AFETR/KSC launch operations personnel, Convair has documented the feasibility of prelaunch operations with a Space Storable Propulsion Module.

In spite of their toxic, reactive, and cryogenic properties, oxygen difluoride (OF_2) and diborane (B_2H_6) or FLOX/methane propellants can be safely used. The 3,000 pounds of propellant, typical for retro propulsion on unmanned outer planet orbiters, can be handled in the same flow sequence successfully used for Surveyor and Mariner. Convair recommends this proven operating plan of tanking in the Explosive Safe Facility Propellant Lab about 30 days before launch because this allows excellent checkouts for maximum assurance of mission success.

Personnel safety can be assured by a number of reasonable precautions. Toxic waste from routine blowdowns during tanking and draining should be neutralized or burned. In case of propellant module leakage, emergency drain provisions are recommended using the supply trailers as receivers. Passivation techniques, including 24 hours at full pressure propellant vapor, have been demonstrated. Thermal control based on a simple ground-based LN_2 system can assure indefinite standby without venting. During propellant passivation, transfer, and pressurization (allowing for the worst case of a rapid cold release of all the oxidizer), reasonable weather restrictions and evacuation radii would be imposed, as is done with the Titan booster. Once the module has been remotely loaded, pairs of technicians can work around the spacecraft wearing splash type suits. Handling a loaded propellant module can be routine for a well-trained crew using careful procedures. Operational support equipment can be simple and dependable.

The Mission Program Office may elect to tank at the launch complex (which is the current Centaur practice) for maximum personnel safety. The period of greatest hazard is during passivation, propellant transfer, and pressurization. Once these dynamic conditions cease, the risk to personnel and hardware decreases progressively as the system remains in a quiescent state. Convair recommends tanking the module once before encapsulation, even though the unit may then be drained and final tanked at the launch pad, in order to minimize the risk to the expensive payload.

Prelaunch operations can have a significant influence on the flight vehicle design. An access door should be provided in the aerodynamic shroud for installation of the radioisotope thermoelectric generator (RTG) and manual access to drain and/or vent the propulsion module. This will minimize the spacecraft launch and in-flight disconnects, which reduce reliability. Accurate propellant weighing is required. Quick demating of an encapsulated spacecraft is recommended. The arrangement of the propulsion module valving is dependent on passivation, purge, checkout, and leakage requirements. As the propulsion system becomes better defined, test techniques and prelaunch checkout methods must be evolved and capabilities built into the design to maximize chances of mission success.

Prelaunch operations using FLOX/methane are inherently similar to those with OF_2/B_2H_6. The fact that methane is not toxic is of little benefit because handling restrictions are determined by the oxidizers. The differential boiloff of FLOX will force the use of more complicated LN_2 jacketed lines and mixing and composition sensing equipment. Similar thermal control techniques are applicable to both propellant combinations. Differences in prelaunch operations are more likely to result from airborne design features such as thin-walled tanks with the pump-fed propulsion systems normally considered with FLOX-methane.

Follow-on studies are suggested in several areas. Perhaps the greatest challenge is the development of really leak-tight propellant shutoff valves and reasonable checkout tests to assure that these valves will function after a 550-day space flight. Thermal insulation systems must be compatible with minute propellant vapor leaks. New hazard sensing instruments for remote, selective indications would be useful on current programs. Toxicity studies should be completed to loosen the extremely tight, currently accepted exposure limits on OF_2.

This study has not uncovered any major technology road blocks, but rather indicates that prelaunch operations will not restrict the development of a space-storable propulsion module.

1

INTRODUCTION

1.1 BACKGROUND

On 16 July 1969, the Jet Propulsion Laboratory (JPL) initiated contract NAS7-742 for the Convair division of General Dynamics to study prelaunch mission operations for a Space Storable Propellant Module. This is part of NASA's Advanced Technology Program concerned with future propulsion systems applicable to unmanned planetary spacecraft such as a 1980 Jupiter Orbiter or a 1977 Mars Orbiter.

The objective of this study is to identify and define any new and/or unique propulsion system requirements in the area of prelaunch mission operations that result from the use of space-storable propellants, oxygen difluoride (OF_2) and diborane (B_2H_6), at the Kennedy Space Center (KSC) and the Air Force Eastern Test Range (AFETR). FLOX/methane is considered briefly to determine any major differences from OF_2/B_2H_6.

These goals are accomplished by outlining the flow of propulsion module flight hardware from arrival at KSC/AFETR until launch, then by identifying and defining those procedures, facilities, ground support equipment and safety precautions that would be required during these operations. This information is translated into new and/or unique requirements upon prelaunch operations and upon the propulsion module arising from the use of these propellants. Conceptual designs are presented for several new AGE units and spacecraft constraints are analyzed.

Space storable propellants are characterized by mild cryogenic temperatures between 155°R and 340°R which is in the range of space equilibrium temperatures attainable near the outer planets. Fuels include methane and diborane and exclude liquid hydrogen by definition. Oxidizers include oxygen, fluorine, FLOX, and OF_2. These propellant combinations generally have a high I_{sp} in the neighborhood of 400 seconds, and a high bulk density. These advantages plus overlapping or close liquid temperatures make possible small compact tankage systems and offer the possibility of vent-free operation. Typical engine performance is based on References 1 and 2.

Table 1-1 lists some of the basic properties of two typical space storable propellant combinations. Diborane is a strong reducing agent, compatible with most metals. It attacks nearly all rubber and plastics except Teflon and Kel-F. Leakage problems have been experienced. Diborane is highly flammable with explosive limits between 0.8 and 98 volume percent. It can be pyrophoric and has a very low, 300°F, auto ignition point. Diborane starts to decompose below room temperature. The vapors are extremely toxic causing "hang-over"-like symptoms and lung irritation. Methane appears relatively straightforward to handle. It is not toxic except in large spill situations. It is less of a fire hazard with narrower flammability limits between 4 and 15 percent, and a high auto ignition temperature of 1200°F.

Table 1-1. Some Properties of Typical Space Storable Propellants

	Diborane B_2H_6	Oxy. Difluor. OF_2	FLOX 82.5%	Methane CH_4
Freezing Point, °R	194.1	89	96	161
Boiling Point @ 1 atm., °R	325.5	230	155	200
Critical Temp., approx., °R	522	380	265	343
Critical Press., approx., psia	581	720	800	673
Liquid Density @ B. P., lb/ft^3	27.2	94	90	26.5
Cost, approx., $/lb	85	30	3	0.05
Reactivity -relative	medium	high	highest	low
Toxicity, threshold limit, ppm	0.1	0.05	0.1	>20,000
Auto Ignition Temperature, °F	293	------	------	1,170
Mixture Ratio, lb Oxid/lb Fuel	3.35		5.25	
Bulk Density, lb/ft^3	63 @ 250°R		62 @ 50 psi	
I_{sp} sec	410 @ 100 psi, ϵ = 60		398 @ 500 psi, ϵ = 70	

Oxygen difluoride is similar to, but slightly less reactive than fluorine or FLOX. Personnel protection must be considered during operations due to the possibility of a burnout of equipment containing the oxidizer. Oxygen difluoride is a lethal gas causing even worse lung damage than fluorine. All fluorine and diborane systems must be kept absolutely moisture free. Propellant thermal data is given in Appendix B.

This study considers handling a propulsion module with 2500 to 3000 pounds of these toxic, highly reactive and cryogenic propellants instead of the 40 to 166 pounds of less toxic earth storables used on the Mariner and Surveyor, programs.

The baseline spacecraft for the operations study is an advanced Viking or Jupiter Orbiter. The launch vehicle is a Titan/Centaur utilizing ETR Complex 41. On the 1975 Viking, the propulsion module will provide mid-course corrections and about 5000 feet per second planetary orbit insertion maneuvers after a 220 day coast. The bus will remain in Mars orbit while the Lander separates and soft lands on the surface. Of the total spacecraft weight of about 7500 pounds, 1800 to 2200 pounds are Lander and 3173 pounds are earth storable propellants with an I_{sp} of 279 seconds in the propulsion module. For a later mission, perhaps 1977, the substitution of OF_2/B_2H_6 with an I_{sp} of over 400 seconds would be a logical advancement, reducing the propellant required and substantially increasing the real payload. Figure 1-1 shows a typical Titan/Centaur/Spacecraft configuration. There is sufficient technology available to assure thermal control of these propellants at about 250°R. A pressure fed multi-start engine up to 1,000 pounds thrust appears feasible. A logical question remains, however, and is the subject of this study: If there are any new or unique problems which will be introduced at ETR by using OF_2/B_2H_6 as spacecraft propellants, what are the feasible solutions?

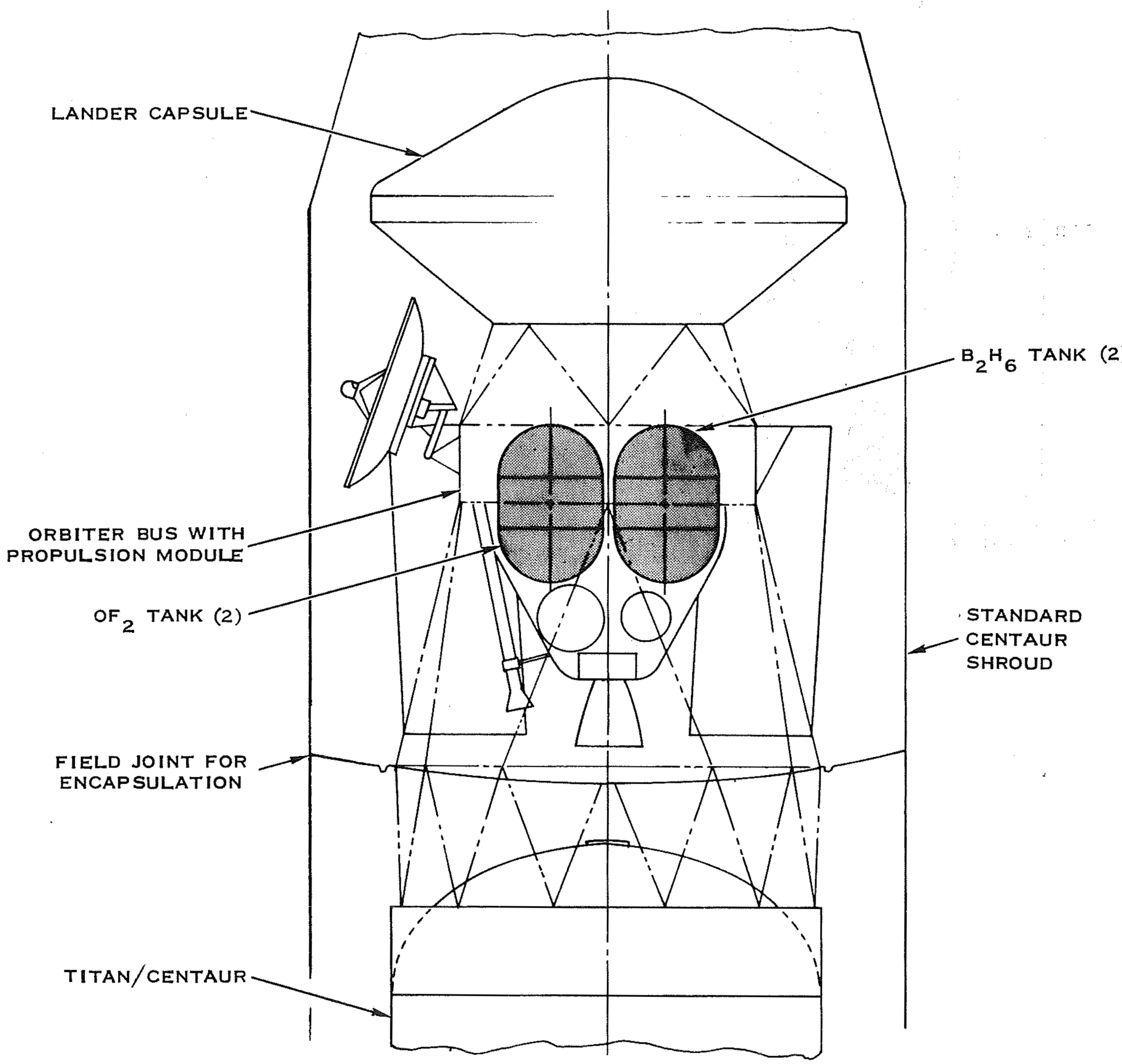


Figure 1-1. Typical Titan/Centaur/Spacecraft Configuration

Figure 1-2 shows some typical planetary retrostages based on studies at NASA LeRC (Reference 3). FLOX-methane configurations are shown with a pump-fed engine. These arrangements are also suggestive of a family of high energy kick stages (HEKS) which have been studied for outer planet spacecraft trajectory injection. While this study uses a particular OF_2/B_2H_6 propellant module as a specific example, the work should be generally applicable to a wider group of space storable propulsion units.

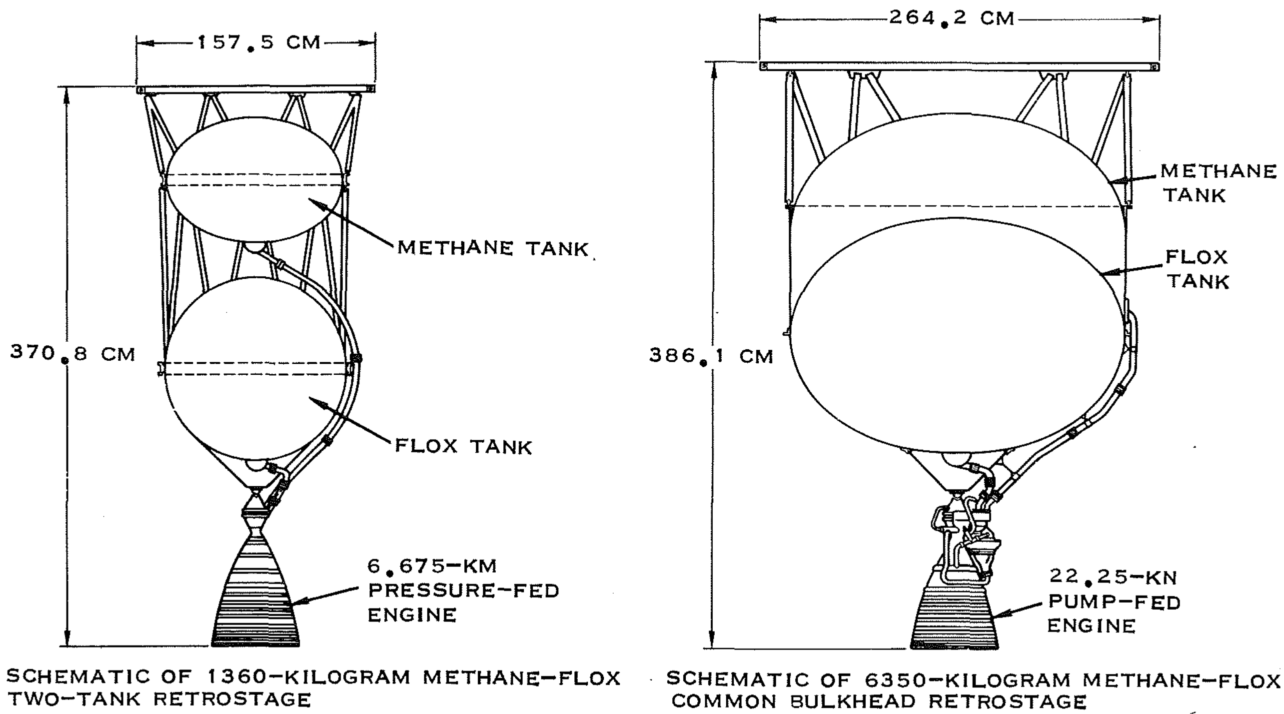


Figure 1-2. Typical Planetary Retrostages

1.2 STUDY GROUND RULES AND ASSUMPTIONS

The primary study effort, which centers on handling an OF_2/B_2H_6 pressure fed propulsion system, is based on the following assumptions:

1. Propulsion module total loaded mass: 3435 pounds.
2. OF_2 mass at launch: 1870 pounds.
3. B_2H_6 mass at launch: 625 pounds.
4. Temperature of both propellants: 220°R at launch, maintained between 210°R and 280°R throughout ground and space operations.
5. Flight tank pressures: 240 psi at launch with a design burst pressure of 800 psi, 100 psi during prelaunch standby.
6. Launch vehicle: Titan/Centaur.
7. The module will perform the following flight functions: midcourse corrections and orbit insertion maneuvers on a space vehicle consisting of a bus and capsule, and orbit trim maneuvers on the bus alone.
8. The bus and propulsion module will not be sterilized.
9. The prelaunch phase of the mission begins with the arrival of flight hardware at KSC and AFETR and terminates at launch vehicle liftoff.
10. Shipment of the mated bus-propulsion module from Pasadena to KSC by truck will occur three months prior to launch.
11. All final assembly, checkout and other prescribed activities to prepare the space vehicle for launch will be performed at KSC and AFETR.
12. The basic flow sequence is:
    a. The bus and capsule will undergo final assembly and checkout in their respective facilities.
    b. The space vehicle will be encapsulated in the shroud, and following this, moved to the launch pad and mated to the Titan/Centaur launch vehicle.
    c. Barring malfunction, the space vehicle will remain mated to the Titan/Centaur through launch. In the event of a malfunction requiring physical access to either the capsule, bus, or bus propulsion module, the space vehicle will be demated on the launch pad and replaced with an encapsulated (in the shroud) flight-ready spare.

d. The assembled and encapsulated space vehicle will be checked out on the launch pad; a flight readiness test and countdown demonstration will be accomplished with the space vehicle on the launch pad.

e. The Titan/Centaur propellant loading and final launch preparations will be accomplished on the launch pad. After completion of the above tests and launch preparations, the final countdown and launch will be initiated.

13. Two basic propulsion module propellant loading modes were considered:

a. Propellant loading prior to encapsulation.

b. Propellant loading on the launch pad, after encapsulation.

14. The time between propellant loading prior to encapsulation in the shroud and launch vehicle liftoff may be as long as thirty days (in case of launch delays).

The second type of propulsion module considered in this study uses a pump fed FLOX-methane propulsion system and was assumed to have the following characteristics:

1. Propellant weight: 3000 pounds.
2. FLOX/methane nominal mixture ratio: 5.25.
3. Oxidizer temperature maintained between 140°R and 180°R.
4. Fuel temperature maintained between 180°R and 230°R.
5. Maximum tank operating pressure: 50 psi.

Figure 1-3 shows the study work plan as it was performed by Convair under JPL direction.

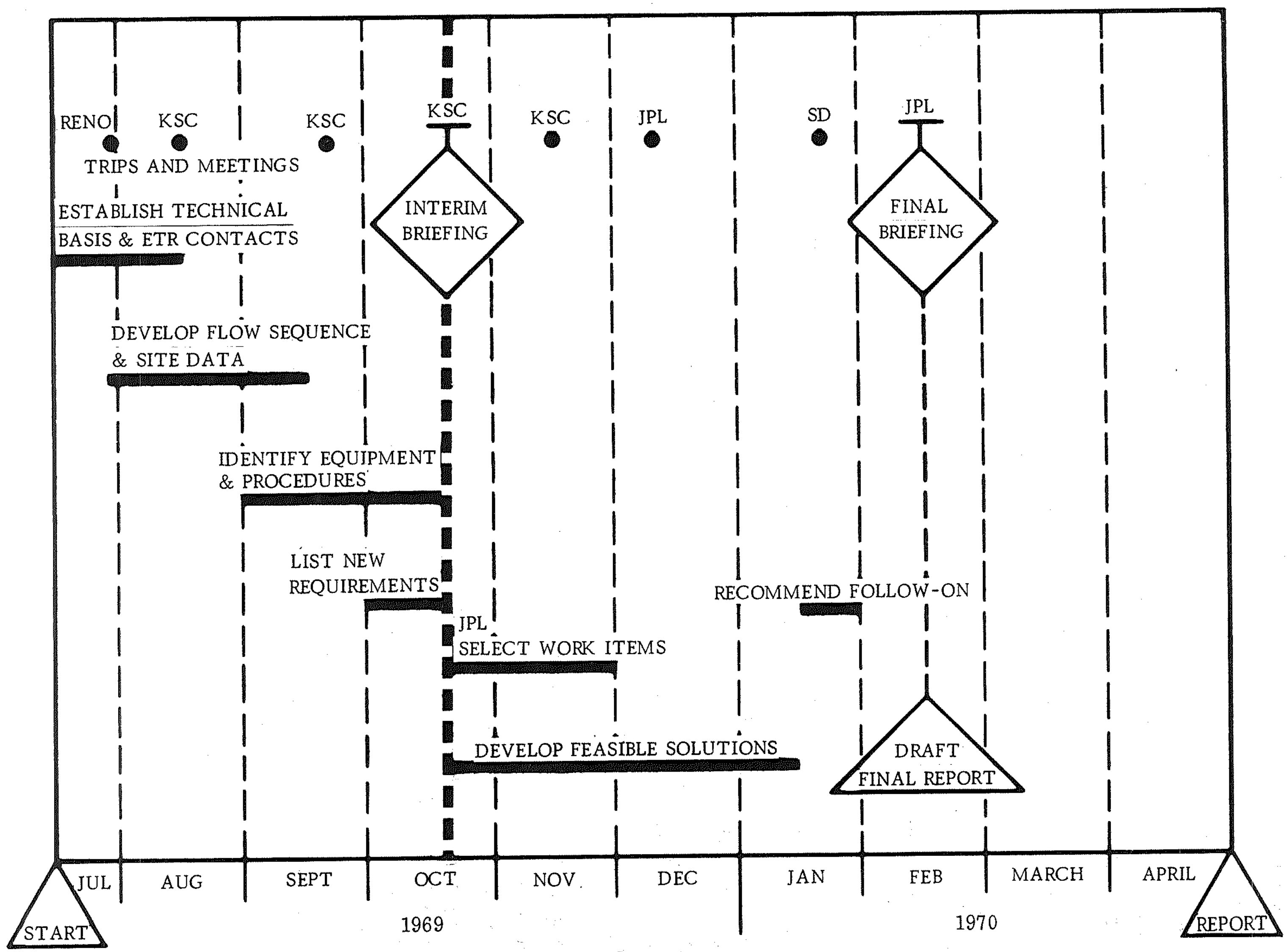


Figure 1-3. NAS7-742 Study Work Plan

1.3 ROCKETDYNE OPERATING EXPERIENCE

Oxygen difluoride, FLOX, methane, and diborane have been in routine use at two different Rocketdyne test facilities for several years. The handling procedures are not the same as would be employed at ETR/KSC because of the different surroundings and different operation objectives. However, the experience obtained provides good background for the establishment of procedures and design of facilities to support launch operations.

Test facility operation involves many dynamic processes with both propellants and these may be viewed from the operational standpoint as extreme-condition propellant transfer operations. Propellants are transferred from shipping containers to storage tanks, storage tanks to run tanks, and run tanks to rocket engines. OF_2 and diborane have been transferred as liquids and gases and at substantially higher pressures and flow rates than are likely to be used in prelaunch operations.

Both propellants have been stored for extended periods. Long-term storage of diborane requires mild cryogenic temperatures, but precise temperature control for ground storage is unnecessary from the standpoint of decomposition; any temperature at or below that of dry ice is adequate. The diborane has been held at temperatures as high as 80°F for several hours and as high as 140°F for six minutes with no evidence of decaborane formation. The diborane has also been deliberately frozen on many occasions during cryopumping operations and occasionally as a safety precaution.

As a general rule, the same safety and cleanliness standards normally applied to fluorine are applied to both OF_2 and B_2H_6. All operations on an active feed system are performed with personnel wearing Graylite safety suits with self-contained breathing air. There have been no uncontrollable failures and no employee has been injured as a result of use of these propellants. Reference 1 gives further test and facility details concerning Rocketdyne's facilities in the high desert north of Reno, Nevada. This remote location was selected so that toxic and highly reactive propellants can be economically tested with a minimum of safety equipment and procedures. Convair and JPL personnel toured this toxic propellant test facility on 28 July 1969 in order to establish a baseline for this study on prelaunch operations.

1.4 CURRENT SPACECRAFT PRELAUNCH OPERATIONS

A number of specialized facilities exist at KSC/AFETR to prepare unmanned spacecraft for flight. Three of the major facilities are: Building AM, Building AO, and the Explosive Safe Facility (ESF). From Figure 1-4 it can be seen that the ESF, Area 60A, is located about one mile north of the Industrial Area which includes buildings AM and AO and Base Cafeteria No. 2. The Centaur launch pads are about four miles to the east, the Titan Complex 41 about five miles north of the ESF. This Titan pad is even more remote being two miles away from Saturn Complex 39A and four miles from the Titan VIB.

Figure 1-5 shows a simplified Viking spacecraft flow sequence starting with non-hazardous electromechanical checks on the payload experiments, telemetry systems, etc., in Buildings AM and AO. Building AM has several air conditioned spacecraft laboratory bays where Intelsat II, ATS, OGO, Pioneer, and Ranger were processed. Building AO was utilized by JPL for prelaunch checkout operations on Surveyor and Mariner spacecraft. It contains a high bay "Class 100,000" clean room 47 by 176 feet, 50.5 feet high. The air lock and overhead bridge cranes are more than ample for Viking size spacecraft. Other facilities are defined in Reference 4.

The ESF serves as an intermediate staging area between the checkout facilities and the Launch Complex in which hazardous spacecraft prelaunch activities are performed. Such activity includes ordnance installation, propellant and pressurization systems tests, and aerodynamic fairing installation. The Explosive Safe Facility Propellant Lab (ESF-PL) is basically a 30 × 36 foot clean room, 35.5 feet high, with banked sidewalls on the side in case of explosion. Figure 1-6 shows the existing ESF plus new additions scheduled for the Viking program. The proposed ESF additions are (1) an air lock on the entrance of the ESF-PL and (2) a new high-ceiling Terminal Sterilization Building (TSB) which accommodates encapsulation operations using the longer Standard Centaur Shroud planned for the Viking missions.

The propulsion module is rolled through an airlock into the Propellant Lab. Mobile propellant carts are brought into the lab and the spacecraft propellant system connected. The actual loading and pressurizing are remotely performed from a control room monitored on TV. After these dynamic operations are completed, and no change occurs for some time, the spacecraft is judged safe to work around. The Mariner was normally tanked five weeks before launch to allow long term monitoring to determine that no hydrazine decomposition was occurring. The facilities, procedures, and personnel have safely handled the 40 pound loads of monopropellant for early Mariners, and the 166 pounds of hydrazine and N_2O_4 used in the Surveyor vernier engine system. For 1971 Mariner, about 900 pounds of these earth storable propellants will be handled here. It is planned to load 3173 pounds of MMH/N_2O_4 into the 1975 Viking Orbiter propulsion module in the ESF-PL and pressurize it to the operating pressure of 242 psig.

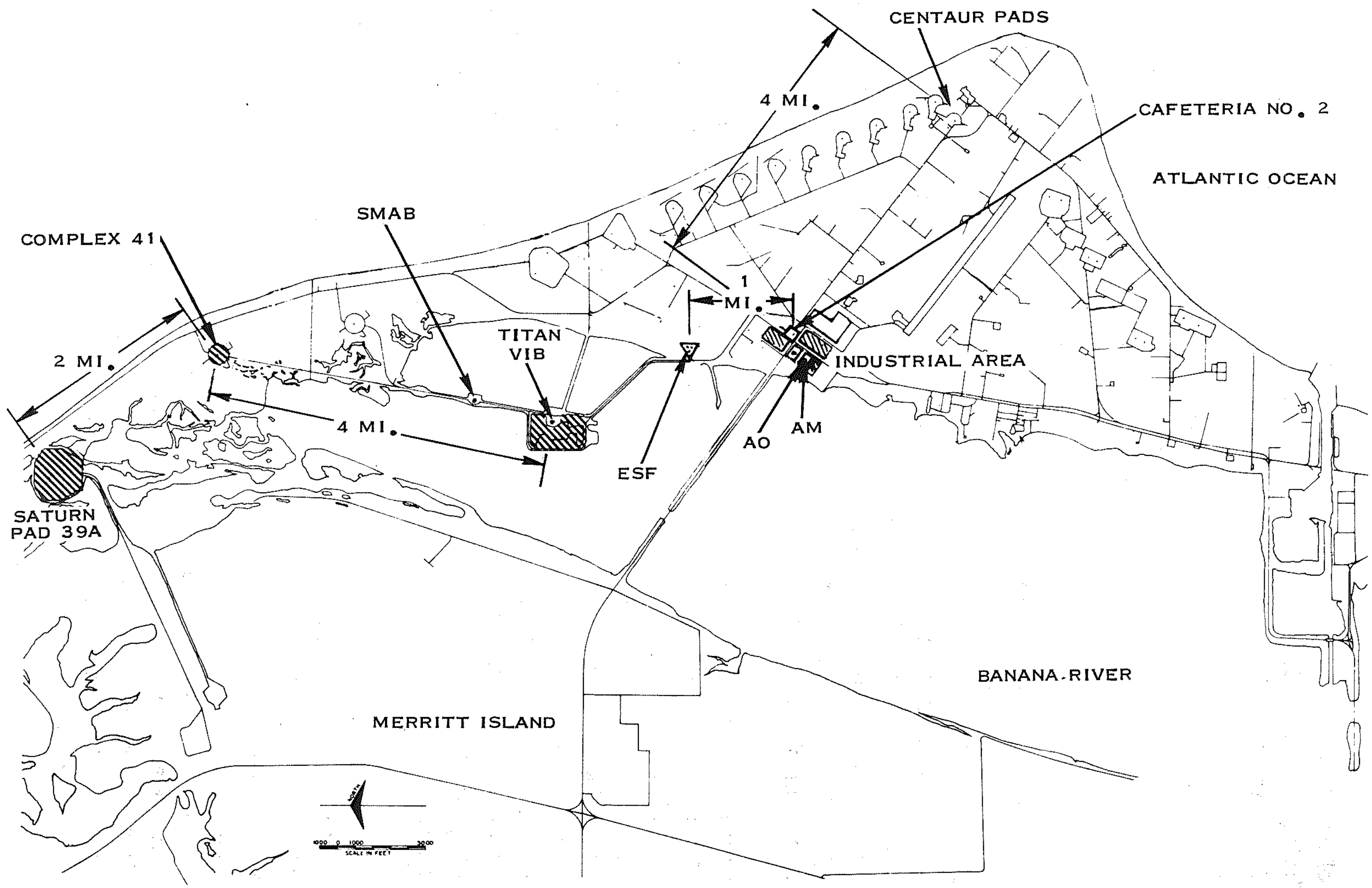


Figure 1-4. Kennedy Space Center

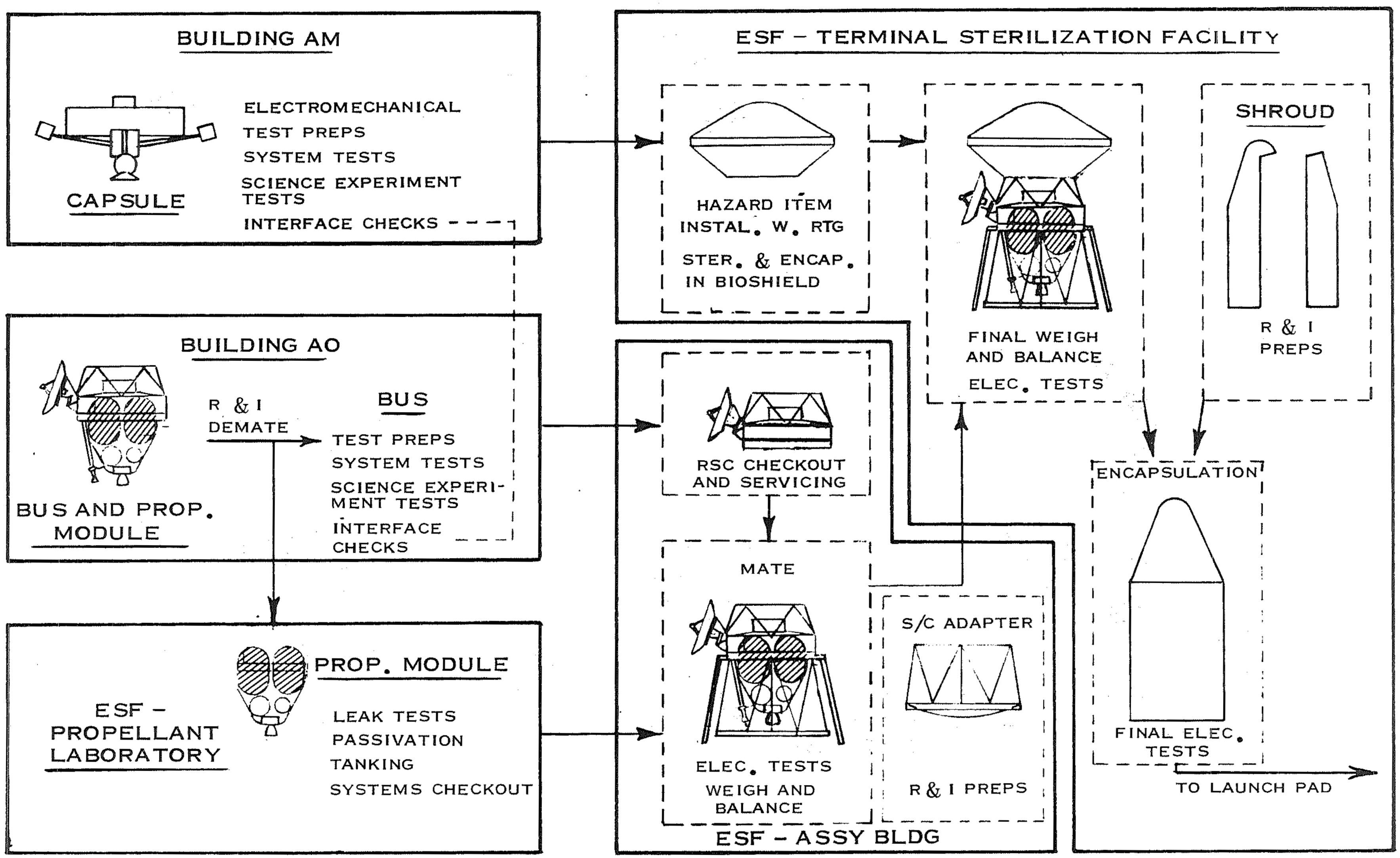


Figure 1-5. Simplified Viking Spacecraft Flow Sequence

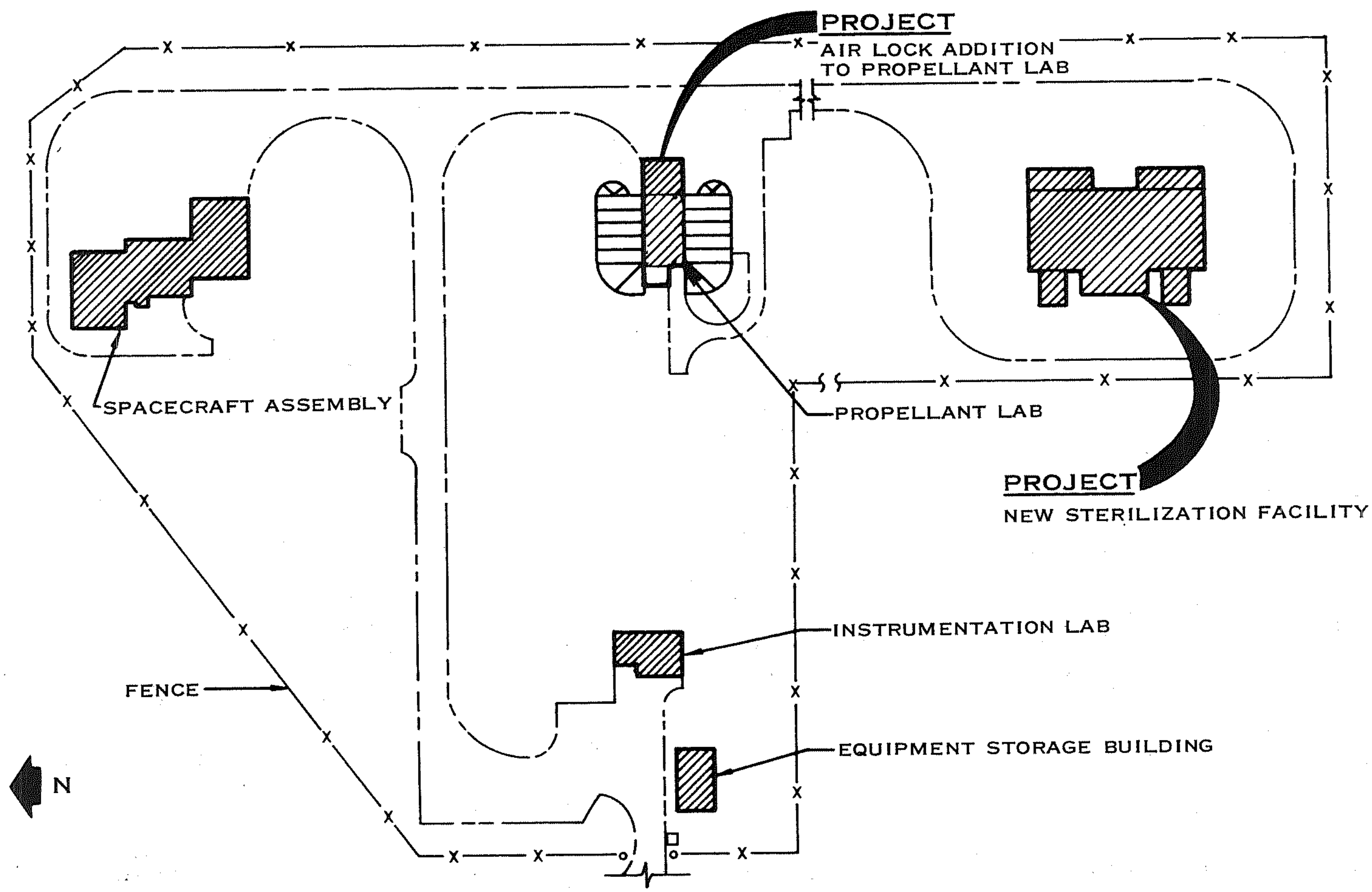


Figure 1-6. KSC Explosive Safe Facility (ESF) with Alterations Proposed for 1975 Viking

After propellant loading and pressurization, the propulsion module is moved to the ESF Assembly Building for mating with the Orbiter bus and then to the ESF Terminal Sterilization Building for mating with the Lander. The complete Spacecraft is then encapsulated in the nose fairing shroud. A thermal bulkhead encloses the bottom of the shroud. Figure 1-7 shows typical dollys and slings required for encapsulation. In the past, encapsulated spacecraft were mechanically sealed and isolated for the rest of the prelaunch operations. The propulsion module, fully tanked and pressurized, could not be drained or vented without removing or cutting into the shroud. A purge or air conditioning cart was run continuously to maintain temperature and cleanliness inside the nose fairing.

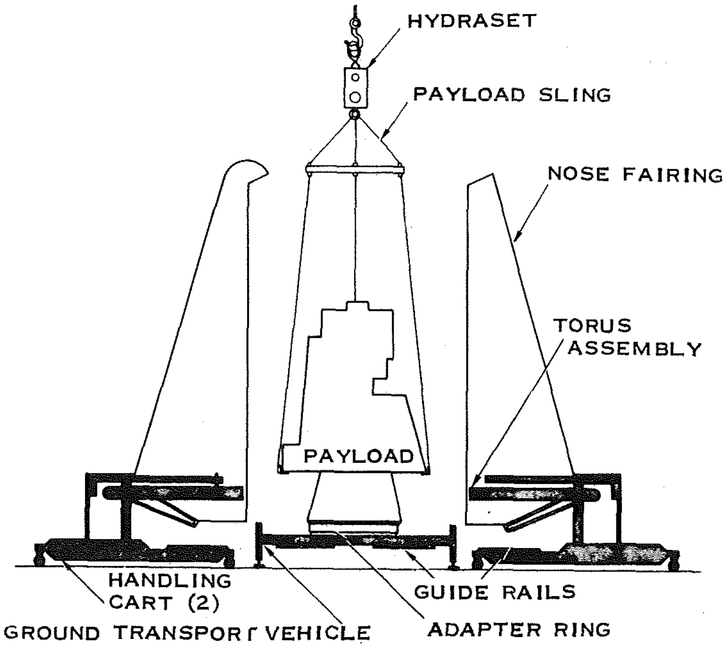


Figure 1-7. Payload Encapsulation Operations

The encapsulated spacecraft is then transported to the launch site in a slow caravan of air conditioning and power supply trailers. Travel distance from the ESF to the Viking launch site is 5-1/2 miles by road. The route is almost completely on a causeway in the Banana River built specifically for the Titan III Integrate-Transfer-Launch (ITL) Facility. No buildings or inhabited areas are passed enroute except the ITL Vertical Integration Building (VIB) and the ITL Solid Motor Assembly Building (SMAB).

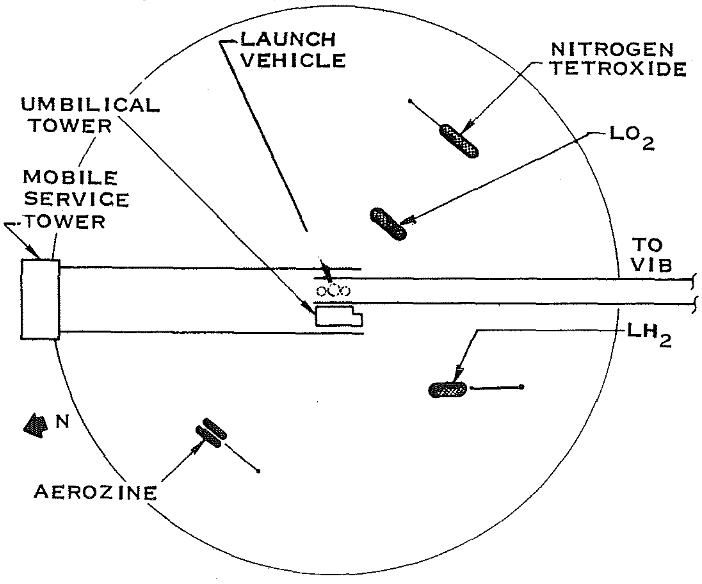


Figure 1-8. Complex 41 Propellant Storage

Most of the Titan III/Centaur Launch Vehicle buildup is done in the VIB. From this building, Launch Vehicle is moved on a rail transporter system through the SMAB, where the Titan III solid motor strapons are added, and then out to the ITL launch site (Launch Complex 41). The encapsulated Spacecraft is lifted up and installed on the Launch Vehicle at the launch site. Overall site layout is shown in Figure 1-8. The Launch Vehicle and Spacecraft are serviced by a fixed umbilical mast and umbilical tower as shown in Figure 1-9. The Mobile Service

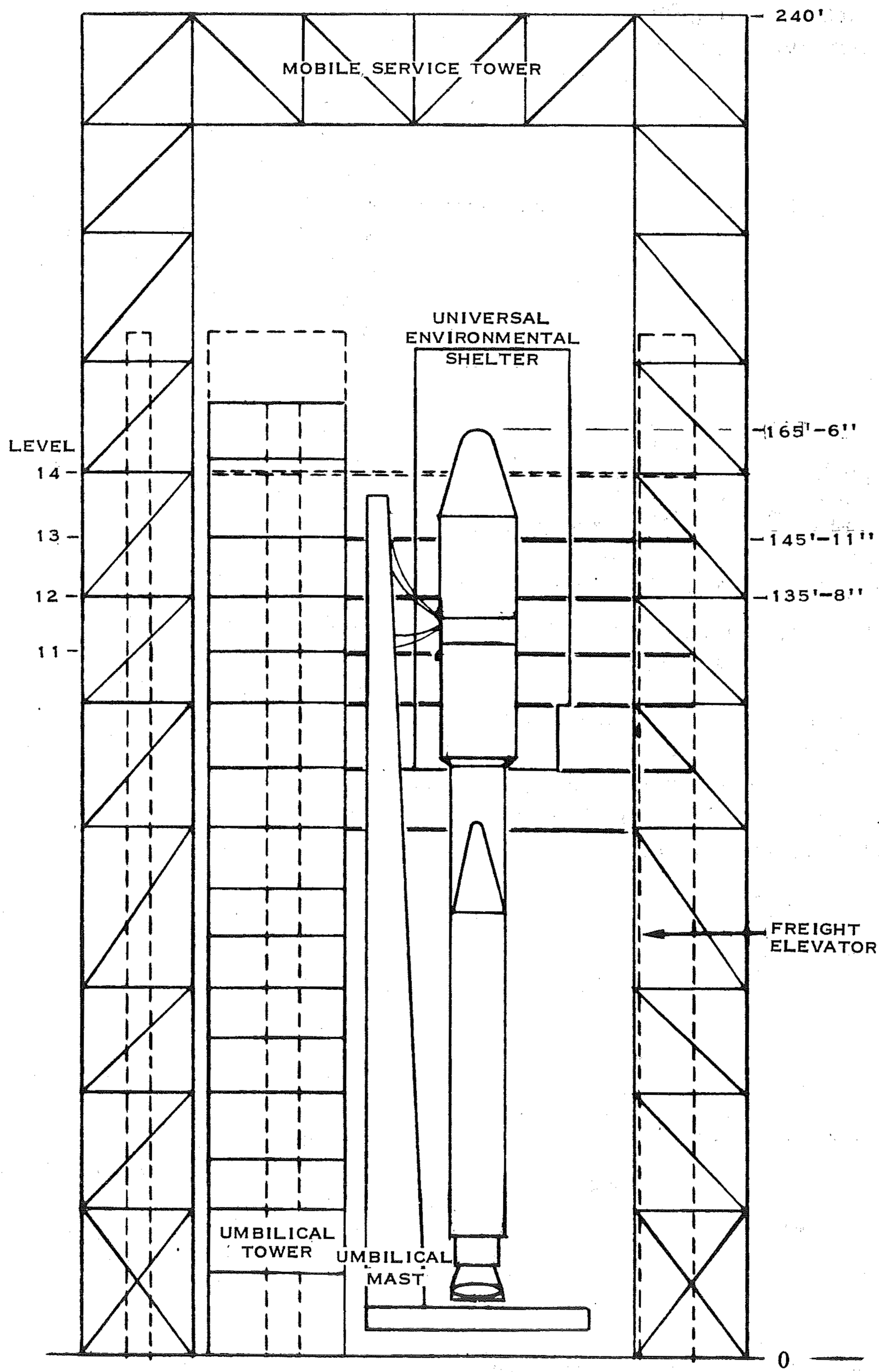


Figure 1-9. Titan/Centaur at Complex 41

Tower encloses the payload area by folding, pivoting walls in a Universal Environmental Shelter as shown in plan view Figure 1-9.

The present Titan propellant loading procedure is to remotely load the Titan oxidizer at T-3 days, then the fuel at T-2 days. During each period, the entire launch area for a 7000-to-8000-foot radius is cleared of personnel. After each loading the operators don complete SCAPE suits until the lines are disconnected and the feed line is secure. SCAPE suits are also worn during manual topping of the Transtage. Then the area is opened to a restricted number of essential personnel. The loading is normally done with a closed system. Stacks for each propellant, about 200 feet high, take care of any necessary venting. Burning is done at the vent for storage loading. Portable piston type sensors are used when the nose indicates a measurement should be made.

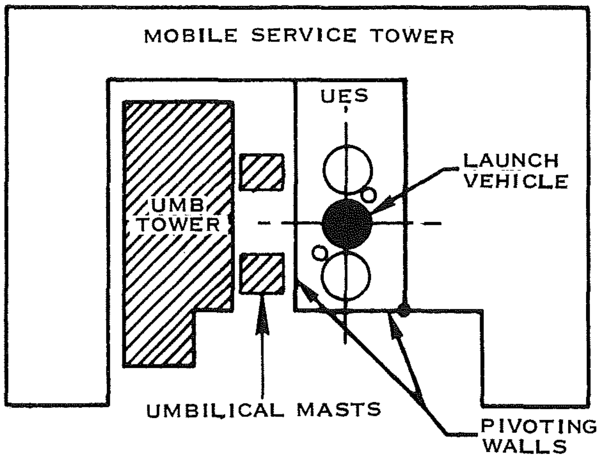


Figure 1-10. Complex 41, Service Level 11

Complex 41 appears well-suited for use of spacecraft toxic propellants. Personnel at the site are experienced in handling large quantities of N_2O_4 and UDMH/Hydrazine, have been thoroughly trained, and have adequate emergency procedures and equipment. Titan final propellant topping is a manual operation, performed by a 12-man crew wearing SCAPE suits. If evacuation is required, the Mobile Service Tower has a stairway and personnel elevator on the west side, and a stairway and freight elevator on the east side. After loading, all personnel in the propellant areas use "splash" suits with face mask and boots.

Deliberate spills of toxic propellants have occurred in the past at Complex 41 without problems. When an abort occurred after T-90, 700 pounds of N_2O_4 was dumped into the flame bucket from the TVC manifolds on the Titan III, to evaporate. The only problem experienced was that the tower ventilation intake pulled the vapors in and discharged them to the payload area where a seven ppm concentration was recorded. The original intake has now been replaced by dual intakes, one north and one south of the pad, with 54 inch ducts running to the fixed umbilical tower. If contamination is detected, ventilation air is automatically switched from one intake to the other.

Both N_2O_4 and UDMH/Hydrazine are stored within the perimeter fence of Complex 41. Two-hundred-foot vent stacks are used for both propellants, venting directly to atmosphere with no scrubbers, burners, or converters. Two hundred foot vent stacks are also used on the fixed umbilical tower. For Centaur, permanent liquid oxygen and liquid hydrogen dewars will be installed at the site.

Table 1-2 shows the typical prelaunch operations flow sequence for the 1969 Mariner spacecraft utilizing Hanger AO for about a month, the ESF for about three weeks, and being mated to an Atlas/Centaur booster about two weeks before launch. The major event at the launch pad is the Centaur hydrogen-oxygen tanking test with accompanying telemetry RF checks. There are also many necessary electrical tests, including the spacecraft interfaces. Final installation of explosive bolts, other pyrotechnics, and probably the radioisotope thermoelectric generator (RTG) units on future spacecraft occurs about one day before launch.

A basic background in prelaunch operations, with emphasis on safety, can be gained from reading "Handbook of Unmanned Spacecraft Operations at ETR," 1 June 1968, prepared by NASA-ULO at KSC (Reference 4).

From these introductory pages, it can be seen that NASA has underway technology programs with space storable propellants which promise increased spacecraft performance. Rocketdyne has been successfully testing OF_2/B_2H_6 at their Reno, Nevada site. Both the Explosive Safe Facility and Titan Launch Complex 41 at KSC have experience in handling toxic propellants. This study, then, is intended to give visibility into any special handling or spacecraft design problems which might result from the particular toxic, cryogenic, and reactive nature of these space storable propellants.

Table 1-2. Mariner '69 ETR Sequence

		Work Days	ETR Area
1.	Spacecraft arrival, inspection and test preparation	4	AO
2.	(a) System Test (included S/P instrumentation alignment verification)	10	AO
	(b) TV calibration reverification	(1)	AO
3.	Mechanical Preparation in AO	4	AO
4.	Mechanical Preparation in ESF	1	ESF
5.	High-Pressure gas leak test	4	ESF
6.	Final Mechanical Preparations in ESF(2)	4	ESF
7.	Electrical Test	1	ESF
8.	Encapsulation	1-1/2	ESF
9.	Electrical Test	1-1/2	ESF
10.	Transport to LC and Mate	1/2	LC
11.	Spacecraft - LC Readiness Test	6-1/2	LC
12.	Composite Readiness Test (CRT)	1	LC
13.	Spacecraft Precount	1	LC
14.	Launch Ready	-	LC
	Total	40	

NOTES: (1) A space spacecraft was mated to launch vehicle during J-FACT and EMI tests (prior to mating of flight spacecraft).

(2) Propulsion modules were physically removed and underwent fueling and leak testing independently from main spacecraft.

(3) Above data applicable to M69-2 and M69-3 flight spacecraft.

2

SAFETY ASPECTS

A prime consideration when working with the OF_2-B_2H_6 propellant system will be safety of men, material and facilities. This caution arises not only from the extreme reactivity of the system which is exemplified by the wide flammability and detonation limits of B_2H_6 and spontaneous ignition of materials on contact with OF_2. It also comes from the corrosivity of OF_2 and the extreme toxicity of both propellants. However, once their special properties are recognized and accepted, it must also be acknowledged that they may be quite safely used when the people working with them have been properly and adequately trained and operations are conducted in a well thought out and very deliberate manner. The Titan program is an example that even very large quantities of toxic propellants can be safely handled. In many ways this booster poses more serious hazards than would a Space Storable Propulsion Module.

Diborane has been handled for a generation in substantial quantities. Hospitalization from exposure has occurred but no deaths have resulted. Fluorine production has also been carried on at industrial levels since the birth of atomic energy. Tanker truck loads are available on short notice. OF_2 can be handled perhaps even more easily.

The next few sections discuss some of the considerations which must be met to safely handle this propellant system, and to cope with emergencies or mishaps that may occur. The measures which must be taken and information used to comply with federal or military requirements for safe operation are also described.

The greatest hazard perhaps is that of fire and explosion. This topic is taken up in Subsection 2.1. Should any of the propellants escape without causing a fire, the concern will be the toxicity for workers. Subsection 2.2 discusses this problem. Even though a leak or fire occurs, personnel need not be exposed to the hazard if they are provided with protective equipment, some of which is discussed in Subsection 2.3. Notice of a potential hazard is sometimes sufficient protection itself. Subsection 2.4 discusses instrumentation for detecting the escape of fuel or oxidant. If a mishap should occur it is important to know beforehand where the toxic vapors will go, how fast they move and what concentrations may be expected. This will allow establishing restricted access limits or barricades, or evacuating prescribed areas. The prediction equation for estimating the probable exclusion area is discussed in Subsection 2.5. Finally the impact of these considerations on the work at hand is discussed in Subsection 2.6. Techniques for safely disposing of leaks or propellant vapor vented during routine operations are discussed in Section 6.1.

The following documents were used to gain a general basic background on the safety aspects of handling OF_2 and B_2H_6 at KSC/ETR:

NASA SP-5032, Handling Hazardous Materials, September 1965 (includes B_5H_9 and LF_2)

DOD 4125.21, Quantity-Distance Standards for Liquid Propellants

DOD 4125.26M, DOD Contractors' Safety Manual for Ammunition, Explosives and Related Dangerous Material, October 1968

AFETRM 127-1 Vol. I, Range Safety Manual, January 1969

AFM 127-201, Missile and Space Safety Manual

AFM 160-39, The Handling and Storage of Liquid Propellants

(USAF) T.O. 11C-1-6, General Safety Precautions for Missile Liquid Propellants

KMI 1710.1, The KSC Safety Program with Attachment A, KSC General Safety Plan

K-V-053, Vol. I, Apollo/Saturn Ground Safety Plan, February 1968

If the properties of the propellants are clearly understood and special precautions and operational procedures carefully and deliberately performed, the propellant combination OF_2-B_2H_6 can be safely and profitably used. At the same time it will be essential to provide for undesirable incidents that could endanger personnel and harm proximate material and facilities.

2.1 FIRE AND EXPLOSION HAZARDS

Diborane is a very flammable gas. It decomposes slowly at ordinary temperatures to yield another highly flammable gas, hydrogen, and higher molecular weight boron hydrides. The decomposition products such as B_5H_{11} and B_2H_4 are more flammable than B_2H_6 for they ignite at room temperature in air and may be the source of spontaneous ignition of B_2H_6 when they contaminate this propellant. B_2H_6 itself ignites in air at less than 300°F and burns with a bright greenish-white light, emitting copious quantities of white smoke (B_2O_3).

The limits of flammability of diborane in air are about 1 to 98, wider even than for hydrogen. The low pressure limit is about 3 mm Hg at 15 percent diborane. The flame speed of B_2H_6 at a fuel-oxidant ratio of 1:1 is about twice that of hydrogen-air. Furthermore, the distance that the combustion wave travels before a detonation wave is established is only about three feet. The speed of the detonation wave is about 2500 meters per second versus 2800 for a stoichiometric hydrogen-oxygen mixture. It is therefore evident that B_2H_6 presents a strong fire and detonation hazard. Methane is much less of a hazard with 1200°F auto ignition point and flammability limits of 4 to 15 percent. Table 2-1 summarizes the flammability of these fuels.

Table 2-1. Flammability of Fuels

Propellant	Flammability Limits in Air (% by Vol.)	Auto Ignition Temp in Air (°F)
B_2H_6	0.9 to 93	300
Aerozine 50	2.0 to 90	450
CH_4	4.0 to 15	1200
H_2	4.0 to 74.2	1075

OF_2 is an oxidant and by itself will not inflame. However, its oxidation potential is so great that it can initiate a flame on contact with almost all organic materials and many inorganic materials. Although it is not hypergolic with water, it does explode when sparked in moist air. Because of its reactivity, contamination can cause evolution of heat leading to flame and explosions. The heat alone may cause a burnthrough of material, which allows the oxidant to leak onto ignitable materials and produce a fire. It is absorbed by activated charcoal but on heating the charcoal may explode. Most reaction products appear white.

The energy of activation of OF_2 for reaction is rather high. It is therefore possible for OF_2 to contact a material a significant period of time before reaction ensues. The delay may allow accumulation of reactants followed by an explosion. Fluorine reacts spontaneously with many materials even at low temperatures or low concentrations, such as 10 percent FLOX. Therefore OF_2 can be considered more hazardous than fluorine in regard to likelihood of explosive reaction.

The sensitivity of OF_2 and B_2H_6 to acting as fire sources makes it mandatory that special care be exercised during all phases of operations with these materials. Standard safety rules and regulations are insufficient to insure protection from hazard. All personnel must be trained in the properties and behavior of these materials and only thereafter may these people and no others operate in and around the propellant systems. The personnel must be trained in safety, health, and fire-fighting procedures as well, for it is not likely that a new system of such high reactivity can become operational with 100 percent freedom from any mishap. First line efforts at fire control therefore is to avoid fires by proper training of personnel in safety, handling, cryogenics, cleanliness, chemical reactivity, protective clothing, material compatibility and hazard sensing.

2.1.1 B_2H_6 FIRE-FIGHTING. Diborane burns in air to give B_2O_3 and water. B_2H_6 and water react to give hydrogen, and hydrogen burns to give water. Water is desirable to wash out the white B_2O_3 cloud produced when B_2H_6 burns. CO_2 is ineffective and may even react with B_2H_6. Halogenated extinguishers such as carbon tetrachloride may form explosion-sensitive compounds. B_2H_6 is normally a gas so foam is not too effective and may even create a lingering hazard of encapsulated diborane bubbles. Ambient diborane vapor will rise because it is slightly lighter than air.

The above considerations lead to the conclusion that the best way to fight a B_2H_6 fire is to let it burn itself out. It is a matter of judgment and evaluation of the situation to use water. Water is an excellent coolant. It can be used to contain a fire and localize it. It is also a good diluting agent and helps in knocking down and washing away toxic products. Another function is preventing the access of oxygen by producing a blanket of steam. Water deluge and water fog or both will at least prevent the spread of a fire if not extinguish it. This may prevent serious loss of men, materials and perhaps a facility.

2.1.2 OF_2 FIRE-FIGHTING. If OF_2 is involved in a fire it is providing the oxidant. The measures to be taken therefore are first to stop the oxidant supply. Normally, this is accomplished by redundant valving. The fuel must also be removed. This involves cleanliness and perhaps training in operating procedures. While a fire is burning, special dry extinguishers based on formulations of alkali salts like Na_2CO_3 can be effective. These have the advantage of neutralizing the fluorinated reaction products. All other agents are capable of reacting with fluorine oxidizers.

The best technique for handling OF_2 fires remains the conventional water application. It warms the cryogenic propellant. It reacts with it to form HF which is water soluble and thus reduces the toxic problem.

Finally, important considerations are the economic advantages to using water, its availability and its compatibility with and application for use against booster propellant fires. No serious changes or additions to facilities are therefore required except possibly fogging nozzles to produce a finer more reactive spray and droplets so that the uncontained propellants are converted to less toxic water soluble products.

2.1.3 EXPLOSIONS WITH CRYOGENIC AND HYPERGOLIC PROPELLANTS. An evaluation of the explosion hazard depends basically on two characteristics: B_2H_6 and OF_2 are cryogenic and hypergolic. A hypergolic system requires only that fuel and oxidizer unite for reaction to occur. It is theoretically impossible to predict what consequences follow or the extent of any ensuing explosion because of many unpredictable factors. Recommendations depend on the results of spill tests, the type of propellants involved and the nature of the mishap such as fall back on launch spill, or powered impact.

A spill of both cryogenic fuel and oxidizer presents a greater explosion hazard than if either alone is cryogenic. The cryogenic fuel B_2H_6 is more hazardous than OF_2 because it can mix with air to form an explosive mixture. The longer the delay before ignition for a given fuel loss, the greater the explosion intensity because of more extensive vapor-air mixing.

On the other hand, hypergolic propellants react with very little delay. Reaction occurs on contact and if the time to contact, or mixing time, is long compared with reaction time no explosion can take place. Furthermore, the extent of reaction depends on the interface area and the pressure developed as a result of reaction tends to separate the propellants.

The explosion hazard of bipropellants and hypergolic bipropellants is obviously quite different from explosions of TNT wherein a homogeneous material detonates. TNT behavior is well known and documented. Protective measures are typically to separate the materials to reduce the amount of damage, amount of loss, lower the overpressures and expend the impact energy of flying debris by distance and by barricades.

The recommended distances for separation require a common denominator for specification. This is done by prescribing TNT equivalents for each propellant or combination of propellants. Once the TNT equivalent is known, the TNT table of exclusion distance may be entered and used as the guide for separation distances. Table 2-2 shows the amount of propellants carried by Titan III, Centaur and a spacecraft. These quantities have been converted to TNT equivalents using Reference 5.

Table 2-2. TNT Equivalents of Booster and Spacecraft Propellants

	Titan	Centaur	OF_2/B_2H_6 Spacecraft
Oxidant, lb	240,000 N_2O_4 (Group I)	25,000 LO_2 (Group II)	1,850 OF_2 (Group II)
Fuel, lb	110,000 AERO-50 (Group III)	5,000 LH_2 (Group III)	650 B_2H_6 (Group III)
Booster, lb	845,000 (SOLID)		
Totals, lb	1,195,000	30,000	2,500
TNT Equivalent of the Liquid	35,000	18,000	1,500
TNT Equivalent of the Solid	40,000		
Total Equivalent	75,000	18,000	1,500

Ref: AFM 127-100, Explosives Safety Manual

The Roman numerals indicate the hazard group to which each propellant belongs as per DOD Instruction 4145.21. Group I presents a relatively low fire hazard. Group II materials are strong oxidizers which exhibit vigorous combustion on contact with materials such as organic compounds. Group III exhibits fragment and deflagration hazards. Each group must be stored alone. If stored together, the more hazardous situation requires that a different table be entered as appropriate.

Table 2-2 lists the propellants and the amounts of each which will be stored. The separation distance for each propellant is given for barricaded storage and for storage intraline, or as it is being used with similar materials in a group. In Table 2-3 the separation distances for the propellant combinations are given for both protected and unprotected (unbarricaded) storage. It is seen from Table 2-3 that storage distances of the propellants in an active system (intraline) are of the order of 200 feet or less. However, toxicity and reactivity considerations require greater separations than this. The explosive potential of the propellants therefore does not present a limiting factor in their use.

In Table 2-4 the TNT equivalents of each stage of the planetary vehicle have been converted to separation distances. It is evident that these are much less than 1000 feet unbarricaded or a maximum of 3,300 feet to other inhabited buildings. Separation distances at ETR Complex 41 greatly exceed these values so no additional protective measures are required.

Table 2-3. Fire and Explosion Hazards Storage Separation Distances of Propellants

Compound	Amount, lb	Inhabited Bldgs, Hwy, Distance, ft. Barricaded	Intraline Distance from Similar Materials ft.
N_2O_4	330,000	170	130
AERO-50	180,000	415	155
LO_2	250,000	330	165
LH_2	15,000	260	95
OF_2	5,500	165	80
B_2H_6	1,600	175	65

Ref: AFM 127-100

Table 2-4. Fire and Explosion Hazards Separation Distances for Vehicles

Vehicle	To Bld's, ft. Unbarricaded	Intraline, ft. Unbarricaded
Titan	3,310	770
Centaur	1,950	490
OF_2/B_2H_6 Spacecraft	920	210

2.2 TOXIC HAZARDS EXPOSURE LIMITS

The use of corrosive, toxic high energy propellants for high performance missions creates the possibility of an accidental exposure of personnel to harmful chemicals. The severity of an exposure is characterized by the concentration of the toxic agent and by the duration.

The concentration which is tolerated depends on the locus of action of the toxicant on the body and the rate at which it can enter the blood stream. Changes effected in the blood, respiratory tract, central nervous system or organs such as liver and kidneys cause the toxic reaction. The longer the exposure, the more extended is the damage.

The duration of exposure will be determined by the type of incident involved, by the suddenness and whether it is expected or not. Protective measures or evacuation can greatly decrease the extent of exposure. The various situations require that different limits be applied to various durations of exposure. There may be insufficient ventilation prior to or after transfer operations during which spills and venting may occur. These exposures are to be expected so that protective clothing must be at hand and rapid evacuation will limit the amount breathed. Fires may ignite and evolve toxic products; evacuation may be accomplished in a matter of minutes in this case. Leaks may occur at joints or valves. Responsive action to this emergency may require exposures of many minutes in order to take the possible corrective actions. Disposal of residue and vent gases may also produce exposures which are low level for many hours. In addition, mishaps may occur at or during launch which originate very high but usually short term exposures.

The local meteorological conditions, sensing instrumentation and structural and engineering features will also determine exposure dosage. These are considered in other sections. Here we are concerned essentially only with the dose levels above which irreversible damage may occur to human beings.

2.2.1 OFFICIAL EXPOSURE LIMITS. The Surgeon General, USAF, is responsible for establishing tolerance levels for both long-term low-concentration tolerance limits and short-term high-concentration tolerance limits. The basic guidelines for the criteria and recommendations establishing the concentration limits are obtained from the American Conference of Governmental Industrial Hygienists. This organization publishes a list of "Threshold Limit Values" which is revised frequently in accordance with new data, reports, experiences and extensive practices and observations which are the basis of fresh judgments.

Table 2-5 shows the relative toxicity values of propellants and some products of combustion of the propulsion systems which may be used for an outer planet mission. The approximate quantity of propellant which will be aboard is also listed. The tabulated threshold limit values (TLV) have been taken from data published in 1969 by the American Conference of Governmental Industrial Hygienists (ACGIH), Reference 6. The emergency exposure limits (EEL) are reproduced from a letter by R. C. Wands, Director Advisory Center on Toxicology, National Research Council, Reference 7, which enclosed values currently recommended. Propellant handling personnel accidentally exposed to the EEL will experience some temporary but non-disabling pain and injury. They are assumed to be basically healthy and trained to recognize toxic exposure and then immediately seek medical care. For the general population, a value 1/10 EEL is used as criteria at AFRPL.

These values contrast markedly with those for OF_2 for short-term exposures. Generally, it has been found that the amounts of fluorine compounds which can be tolerated for short periods are greater by an order of magnitude than the initial values proposed. As experience is obtained with OF_2, tolerance values for short term exposure are expected to reach those for ClF_5 at least. This is a favorable trend because the type of exposure expected for these non-vented propellants is expected to be short-term only.

Fluorine values are based on the work of Dr. Keplinger, Consultant Toxicologist, Gainsville, Florida, who submitted his recommendations to the American Industrial Hygiene Association. Official sanction is an undefined procedure. The burden is on NASA to gain the approval.

Technical societies have no official status, but their recommendations establish the basis for official acceptance of limits. The AIGH or ACGIH recommend limits to the Director (presently Dr. Ralph C. Wands), Advisory Center on Toxicology, Division of Chemistry and Chemical Technology, National Research Council. The director in turn, on the basis of experience and judgment prevailing in his division, passes these recommendations on to the Surgeon General of the Air Force who can make the recommendations official. These "official" values are then used to guide the range safety officer who has the final responsibility for site safety and emergency procedures. This is not under NASA control.

Table 2-5. Relative Toxicity of Propellants and Products

Substance	Amount lb	TLV		EEL ppm		
		ppm	mg/m^3	10 min	30 min	60 min
OF_2	1,850	0.05	0.1	0.5	0.2	0.1
B_2H_6	650	0.1	0.1	10	5	2
NO_2 (or N_2O_4)	250,000	5	9	30	20	10
N_2H_4 (skin) Hydrazine		1	1.3	30	20	10
$(CH_3)_2NNH_2$ UDMH				100	50	30
Aero-50 (Aerozine)	110,000	0.5				
HF	pdt	3	2	20	10	8
B_2O_3	pdt	20 grams		1000 mg/m^3	400	200
F_2	ref.	0.1	0.2	15	10	5
BF_3	pdt			10	5	2
ClF_3	ref.	0.1	0.4	7	3	1
ClF_5 (Compound A)	ref.			3	1.5	0.5

TLV Threshold limit value. Time weighted value for continuous exposure for eight-hour day, 40-hour week.

EEL Emergency exposure limits. Maximum allowable for short periods of time.

Source: References 5 and 6.

Note that the allowable concentration of OF_2, based on limited experience, is 30 times less than pure fluorine and 6 times less than Compound A for 10 minutes.

For this study, Convair contacted Dr. R. C. Wands, Director of the Advisory Center on Toxicology of the National Research Council, Mr. Rudy Marazzo, Chief of Environmental Health at NASA, Washington, and Dr. H. E. Stockinger, Chief Laboratory of Toxicology and Pathology, Bureau of Occupational Safety and Health, Department of Health Education and Welfare. The values of TLV and EEL presently used have been provided by them and are presently as official as the data can get. The Air Force functions through its Toxicology Laboratory at Wright-Patterson Air Force Base where the work on Aerozine was done in-house.

2.2.2 PHYSIOLOGICAL AND ECOLOGICAL HAZARDS. OF_2 is a highly reactive cryogenic oxidizer. When a cryogenic compound impinges on skin it produces a burn similar to a thermal burn and is treated the same way. Usually a chemical reaction will also occur with the skin. This leaves toxic fluoride ions in the damaged area so that the cells die and healing is difficult. Unless the F ion is deactivated, gangrene can ensue.

If a powerful oxidizer like OF_2 is inhaled, the lung tissues are corroded and destroyed. The high heat of reaction alone may cause damage. Pulmonary edema is a natural consequence. Some OF_2 may also enter the blood stream because its high energy of activation delays the reaction. Here it may interfere with the oxidation-reduction balance and quickly lead to death by interfering with normal metabolism. Approximately 10 ppm OF_2 for 10 minutes would probably be fatal. Long term exposure to low fluorine levels above 0.1 can induce osteosclerosis, loss of hair, anemia and bone and ligament changes.

Diborane is a powerful reducing agent. It irritates the lungs and seriously impairs the central nervous system, possibly by its effect in blocking oxidation-reduction enzymes. Symptoms are headache, nausea, and chest tightness.

The odor is a protection but small concentrations may be below the threshold limit for detection by the nose. Timely treatment with depressants or barbituates is helpful.

Many exposures to toxic concentrations of diborane have occurred. Hospitalization has been required for numerous cases. To date, there has yet to be recorded a human fatality. Evidently, prompt action to neutralize the blockage causing central nervous system deficiency and care in restricting pulmonary damage leads to expectations of complete recovery from even serious exposures with no permanent damage.

There is little definitive knowledge on the effects of OF_2 on plant life. Many reports exist regarding the effect on plants of fluoride emissions from smelters. The mechanism of damage other than surface effects is not known. Documentation is limited to statistical observations of the nature and extent of damage.

A study was made of the effect of OF_2 by Dost et al (Reference 8). They report no damage to aquatic animals and plants because OF_2 is relatively insoluble in water.

This characteristic and its relative stability, however, also results in persistence until it is decomposed by reaction with water or blown away. The HF resulting from hydrolysis is itself toxic.

OF_2 is slowly fatal to mammalian life following exposure to 15 ppm for 10 minutes. Death is caused by failure and destruction of pulmonary cells. When plants were exposed to three ppm, the surfaces lost their pigmentation and metabolic dessication occurred. At 100 ppm contact reactions cause tip burning and rapid bleaching. Yet operation of fluorine engines by Bell Aircraft at Buffalo showed no great damage to plant growth near the site. Obviously, no precise or definite conclusions or recommendations regarding ecological effects under missile operating conditions may be made at present.

Boron as B_2O_3 has also been shown to be toxic to plant life. Its effects are not as immediately evident but are shown by decreased germination frequency, inhibited growth, lower crop yields, leaf curling and cholorosis. Application of the oxide to foliage produces a greater toxicity than a similar amount in the soil only.

2.2.3 RECOMMENDED TOXICOLOGICAL STUDIES. In view of the lack of extensive experience on the toxicity of OF_2 and other fluorine compounds and the cessation of study of B_2H_6 with the loss of interest in boron fuels in the 1960's, it is now pertinent that gaps in our information be filled. For this reason it is recommended that additional studies be made which are designed to generate better data for these propellants but particularly for OF_2. The chief basis for the OF_2 hazard lies mostly in a single work by LaBelle et al in 1945 at a time when the purity of OF_2 should be questioned (Reference 9).

In particular, it is recommended that new experiments be undertaken to evaluate tolerance limits applicable to short-term high concentration levels of propellant. Measures to protect the general population from the Threshold limit values will be taken. This will be done by one or more of the following means:

1. Restriction on operations depending on wind and weather.
2. Emergency dumps.
3. Design of hardware - non-vent lines, diked spill areas, and other propellant confining configurations in the vehicle.

However, the possibility of exposing operating personnel remains to be provided for. According to Reference 10, the EEL limits anticipate some degree of discomfort and injury, but are of a temporary and non-disabling nature. Exposed personnel should not be subjected to further exposure until so authorized by a physician.

Experiments may fall along the following lines with rats as test animals. Such a program is relatively standard and should not cost more than $20K.

1. Assemble 500 rats having roughly equal weights.

2. Prepare standard atmosphere for exposing the rats to OF_2 concentrations from 0.1 to >20 ppm.

3. Divide the rats into groups of 20. Use 20 rats per exposure and 20 for control to permit statistical analysis of data.

4. Expose the groups to the test concentrations of OF_2 for periods of time from one minute to four hours.

5. Sacrifice half the test group and observe the other half after the test for each group tested. Analyze the sacrificed animals for type and amount of damage with regard to impaired function and damage to external and internal tissues and organs.

6. Determine the LD_{50} - the dose at which 50 percent of the animals die. Compare with relative toxicity of known compounds. Extrapolate data to probable damage or injury to humans.

2.3 PERSONNEL TRAINING AND PROTECTIVE CLOTHING

Regulations concerning the conduct of toxic propellant operations and the wearing of protective clothing must be established and enforced. All personnel who may be exposed to toxic material through skin absorption or contact must be thoroughly instructed in propellant safety and familiarized with types, use and wearing of the protective clothing issued to them. Nearly everyone at Complex 41, and also at the ESF if B_2H_6 and OF_2 are handled there, will have to be badged as qualified to be around the propellants, showing that they have been trained in safety and emergency handling procedures for propellants. Spacecraft review teams and other visitors would require trained escorts. Such a training program involves the following elements:

1. Orientation
   a. Physical and chemical properties of B_2H_6 and OF_2.
   b. Advantages of propellants.
   c. Safety, first aid, emergency procedures.
   d. Special equipment.

2. Demonstration
   a. Properties of OF_2 and B_2H_6.
   b. Specific first aid - materials and equipment.
   c. Reaction with propellants and materials.
   d. Exam.

3. Certification

   a. Specific procedures - load, transport, store, purge, passivate, connect, assemble.

   b. Test on propulsion module simulator.

   c. Final written and practical exam.

The Propulsion Module Simulator or test article will be functionally the same as a flight article, but built with more conservative safety factors and without non propulsion systems such as telemetry or experiments. This test article can be passivated, loaded, pressurized, vented and drained using actual flight hardware procedures.

At the Rocketdyne facility near Reno, toxic propellant line connection and transfer from trucks or shipping containers is manually done by a few men in Graylite suits with breathing equipment, while all other personnel are evacuated. Each employee working at the site is given a propellant safety and familiarization course. Safety drills are performed without warning to assure that each person knows his assigned task.

At the Cape Kennedy ITL facility, a fully protective environmental suit called SCAPE (Self-Contained Atmospheric Protective Ensemble) is used in the handling of N_2O_4 and UDHM/Hydrazine. It has a self-contained air supply that utilizes liquid air for both breathing and temperature control purposes. The air supply has an approximate average duration of one hour, plus the reserve. The suit is made of butyl-coated dacron, the boots of vinyl and the gloves of polyvinylchloride. The head piece is an integral part of the suit and incorporates a contoured hard hat. Titan Transtage propellant topping-off is a manual operation, performed by a 12-man crew wearing SCAPE suits. The Mobile Service Tower has a stair and personnel elevator on the west side, and a stair and freight elevator on the east side, if evacuation is required. After loading, anyone in a propellant area uses a "splash" suit with face mask and boots.

A protective suit should possess the following minimal properties. The boots should have no exposed metal parts and should be soled to prevent slipping. Safety goggles or fully protective eye shields should be worn at all times. These should not be composed of flammable plastics or those which soften in heat or solvents. Asbestos based clothing must be worn by those exposed to flame hazards. All materials should resist buildup of static charges.

Typical light-weight clothing might consist of shirts, trousers, shorts, caps, socks and undershirts of vinyl coated Dacron or Dynel fiber. Glove may be Neoprene or Butyl rubber. A suit composed of Nomex, a special nylon fiber, is successfully used by Rocketdyne as a splash suit. The nylon is impregnated with Teflon. This resists fluorine oxidizers impinging on it long enough for a man to get away from the area.

Boeing is reported to have developed a Teflon suit coated with Teflon fabric which could be expected to serve excellently against fluorine propellants. It is 97-001 Armalon with Teflon threads and coated with Teflon. This suit exhibited good wear and good corrosion resistance.

AFRPL has tested a DuPont experimental material designated 175-173-1. This material, which was one of many tested, showed satisfactory resistance to fluorine and ClF_5. It survived a 50-psi impingement pressure for 15 seconds. AFRPL has found a contractor who is now fabricating the material into a SCAPE type suit. If the fabricated material holds up as well as it has in tests to date, a satisfactory suit with self-contained breathing protection will be available for use with the propellant system under discussion.

Respiratory devices must be a part of the safety clothing if significant exposures are to be resisted. For slight or intermittent exposures, a chemical cartridge type of respirator may be used. For appreciable concentrations where exhaust ventilation is insufficient to remove the gas, air masks, canisters of self-generating oxygen or helmets may be used.

For extreme conditions, the clothing must be impervious to the gas and the air supply must be self sufficient. This may be in the form of a air hose, an oxygen or compressed air cylinder, a self-contained regenerative demand type breathing apparatus or a self-contained complete atmospheric support system. This last type of suit is required especially where rescue work or emergency repair work must be done in excessive concentrations of irritating or corrosive materials.

Figure 2-1 shows the important design features of a particularly useful type of SCAPE suit. This suit should be made of Teflon-coated Teflon fabric with an asbestos inner layer for fire protection. The headpiece is an integral part of the suit and incorporates a contoured hard hat. The suit is designed with an air distribution system inside the suit. It is compatible for use with a gyro back-pack, umbilical tubes, or filtered force-fed air. Even though the outer layer is ruptured, a layer of air and fabric still protects the wearer. It is reported to be light, and to offer minimal restriction to movement and not excessively awkward to wear. Development was done at U.S. Army Natick (Mass.) Labs (Reference 11).

The SCAPE suit is suggested as the ultimate protection for rescue and emergency work. However, the best protection is still to leave the area. It is therefore better to wear protective clothing which is readily removed for immediate protection. This immediate light weight protection would include eye, body, hand, and foot protection. The fabrics, in order of decreasing cost and protection are Teflon, Nomex and Neoprene. This protection together with a firm training program on emergency plans and procedures would serve for all but unexpected emergency situations.

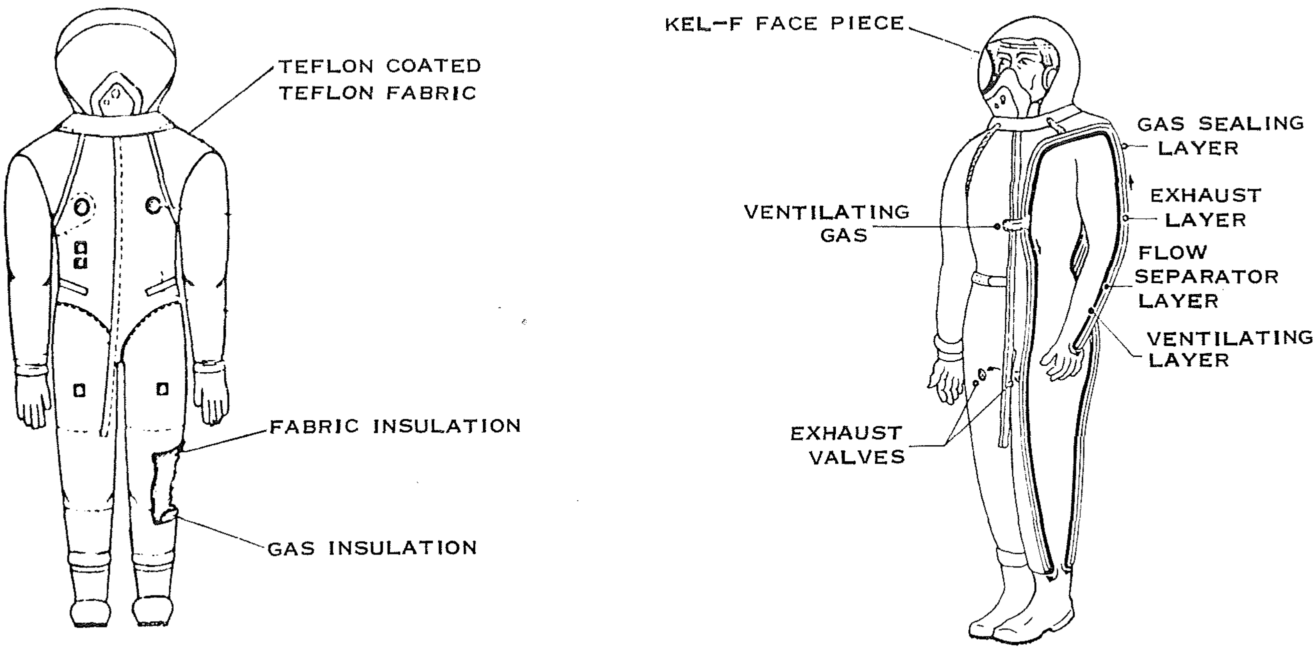


Figure 2-1. Explosive Ordnance Disposal Protective Suit

It is felt that the modified SCAPE equipment is best suited for handling OF_2 and B_2H_6. For any manual corrections into the airborne or ground propellant systems to fill, drain, sample, purge or pressurize or for disaster or clean-up operations, SCAPE type equipment would be used by pairs of workers. Once the space storable propellant module has been loaded and leak checked, nearby technicians need wear only a splash suit with quick release frontal apron, throw-away hood and canister mask.

2.4 PROPELLANT VAPOR DETECTION INSTRUMENTATION

Oxygen difluoride and diborane are each very toxic reagents which are detectable by odor. This provides a measure of protection by signaling a potentially hazardous situation. However, excessive or prolonged exposure deadens sensitivity or damages tissues so that reliable instrumentation is required for safety. Also, area monitoring is required to sense leaks or malfunctions in remote areas when no one is nearby.

There are simple inexpensive rapid tests for gross leak detection. An ammonia squirt bottle shows leaks by generating white fumes. Potassium iodide paper turns to a shade of red in the presence of OF_2. There are also other available paints and papers which change color in the presence of strong oxidizing agents, fluorides or halogens. Mine Safety Appliances, Harrold and Kitagawa offer piston operated instruments based on these principles. Such portable, handpumped instruments are used during Titan topping operations.

Test apparatus using fluorine oxidizers will usually have wire detectors wrapped on sensitive areas such as joints and gaskets. Leaks or impingement of the oxidizer burns the wire which causes a relay to shut off the oxidant flow at the source, thus limiting damage. Paper tape wrapped at selected locations will also indicate leakage by exhibiting a burned, discolored or deteriorated appearance.

2.4.1 INSTRUMENTS FOR OF_2. It is impossible to purchase a commercial OF_2 detecting instrument. However several instruments used for fluorine tests may be adapted for OF_2 monitoring. They are compared in Table 2-6. Some units tested are:

1. Davis HF Indicator-Recorder

   This instrument measures the conductivity of a stream of water through which the atmosphere is bubbled. It is therefore sensitive to all environmental contaminants which form conducting ions in solution. Few of these have seen service. (Model 11-7010-RP Special, Davis Emergency Equip. Co., Newark, N.J.)

2. Tracerlab Fluorine Indicator-Recorder

   This instrument has a sensing element of krypton-85 quinol clathrate. Exposure to fluorine releases the krypton-85 which is measured with a radioactivity counter. This instrument is also sensitive to moisture and other materials which may solvate or decompose the clathrate, but compensating adjustments may be made (Model FM-2, Laboratory for Electronics, Inc., Waltham, Mass.).

3. Convair Fluorine and Fluoride Dosimeter

   This instrument measures total integrated fluoride and is not adapted to continuous real time monitoring (Model 00509).

4. Convair Electrochemical Molecular Fluorine Indicator-Recorder

   During Convair's work in connection with Atlas-FLOX compatibility (Reference 12), a fluorine detector was developed that is capable of detecting concentrations in the ppm range. This instrument may be expected to be applicable for OF_2 detection with a suitable adjustment of pH and solution.

   In the instrument, sampled air is bubbled through a chloride solution. Chloride ion is displaced and is oxidized at the anode. Two electrons flow through the electrical circuit to the cathode where the oxidized chlorine is reduced to the ion. Hence the current is proportional to the amount of fluorine present. This current is easily measured so that the instrument is specific and selective because only fluorine oxidizers (and perhaps ozone) give this reaction (Model 00510).

Table 2-6. Comparison of Available Instruments

Manufacturer	Type	Limitations
	OF_2, F_2, or FLOX	
Mine Safety Appliances	Ionization chamber (Billion-aire)	Non-selective; responds to any acid species; saturates
Tracerlab	Krypton-85 clathrate	Cell life limited; AEC license needed; humidity interferes
Teledyne	Fuel-cell, electrochemical	Other oxidizers interfere; humidity interferes
Davis	Thermal-conductivity	Responds to any ionic species rather costly; heavy
Mine Safety Appliances, Kitagawa	Piston operated; colorimetric	Point source; no remote operation; not continuous
	B_2H_6	
Mine Safety Appliances	Ionization chamber (Billion-aire)	Not selective, saturates, responds to any aerosol forming agent; fixed
Mine Safety Appliances	Piston operated; colorimetric	Point source; not continuous; not remote; fixed

5. Teledyne Recorder

   This instrument operates as a fuel cell. A steady state current is set up. The presence of oxidant perturbs the equilibrium of a bridge circuit and signals leaks. Moderate humidity affects this instrument greatly (Model 5100).

6. Thomas Fluorescent and ADAK Colorimeter Instruments

   These instruments have been used but are heavy, bulky and not as sensitive or convenient as those mentioned.

TV coverage during transfer operations aid in detecting gross leaks quickly and cannot be overlooked in any scheme of instrumentation. This is a passive system and requires continual attention from an observer to be useful.

All of these instruments and techniques are capable of being upgraded to increase their sensitivity, selectivity, reliability, stability, and to reduce their cost.

2.4.2 INSTRUMENTS FOR B_2H_6. The experience with diborane has not been as extensive as with fluorine so that no B_2H_6 selective instrument is available at present. Techniques and methods are available for making this measurement but again, it is desirable to increase the sensitivity, selectivity, simplicity, and stability. See Table 2-6.

1. Mine Safety Appliance Billion-aire

   This is the most applicable instrument presently commercially available for B_2H_6 measurement. This instrument consists of a radioactive source which ionizes a stream of air from the sampled environment. The ion current produced is steady unless a contaminant is present. Contaminants react with reagents in the machine to form aerosols which change the ion current. The change in ion current is then a measure of the concentration of contaminant. This instrument is sensitive to any materials which affect the ion mobility or quantity. This is a large bulky non-portable instrument.

2. M.S.A. Pump Kits for Sampling Atmospheres

   The number of strokes on the instrument required to change the color of a sensitive reagent is a measure of contaminant concentration. These instruments have no remote readout and are affected by many interfering substances which may change the color of the sensor material. Rocketdyne uses this instrument after a run at their Reno, Nevada site to manually check that the area is safe to re-enter.

2.4.3 RECOMMENDED INSTRUMENT DEVELOPMENT. There is considerable room for improvement for both OF_2 and B_2H_6 detectors. The sensitivity of the electrochemical or fuel-cell type instrument is particularly attractive if a reagent is found which can be affected only at the high redox potentials characteristic of OF_2 and B_2H_6.

The mass spectrometer is not as sensitive as the electrometric type instruments, but it is capable of providing readouts for both propellants at once. Space age technology is also bringing the size and cost of these instruments to a level where this application can be considered.

Although OF_2 is one of the most powerful oxidizers known and B_2H_6 one of the most powerful reducers, it is strange that adequate selective sensitive detectors are not available. A reason of course is the presently exotic nature of the materials. They are also very toxic, corrosive and reactive and so have been handled by specialists or trained personnel. It is theoretically possible to find a specific reaction or behavior by means of which each may be detected selectively. The need has not been sufficiently pressing to date to encourage the commercial development of instruments or laboratory models which satisfactorily fulfill all the possible requirements at a launch site. We recommend their development. One of the guiding principles in the choice of a method is that it should be adequately sensitive. Official maximum threshold limit values have been established for these propellants. These limits should not be exceeded where men are continuously exposed for eight hours each day. The method used should be sufficiently sensitive to measure such concentrations, which means less than 0.05 ppm by volume for OF_2. It is rarely necessary that quantitative results have a precision greater than ±10 percent, but it is essential that an acceptable degree of precision should be attainable at the threshold limit value however low it might be.

It is desirable that the method be simple and not require elaborate apparatus or a skilled technician. But this simplicity of operation should not be gained too much at the expense of specificity and precision. It is preferable that other substances in the atmosphere not affect a reading, although from a safety point of view, an interference giving rise to a high reading is less serious than one which produces a lower reading. Permanent installations (not portable) can tolerate more complex apparatus which provide high sensitivity, specificity and accuracy and require skill to operate them. At times it may be just as wise to have a simple, rapid, but not very precise procedure which is capable of giving a warning of excessive atmospheric concentrations.

A single figure does not define the extent of a hazardous concentration for it will vary with time and location. Ideally a complete volume would be monitored. This is impossible so that sampling probes or inlet tubes must be judiciously located and sampling performed as often and as long as can be arranged. By integrating the dosages in this way a more precise picture of transient high concentrations can be disclosed and the hazard better defined. Continuous recording of concentrations from many instruments, sampling many points, would be even better of the apparatus were simple and inexpensive. With these principle in mind, the requirements in Table 2-7 may be proposed as a goal from a recording instrument. An evident incompatibility resides in the spread of seven orders of magnitude in the range of concentrations which the instrument is capable of detecting and the least concentration to which it is capable of exhibiting a response. While acknowledging this lack of capability in any instrument or method of which we are aware today, it may nevertheless remain as a desirable goal.

2.5 ATMOSPHERIC DIFFUSION

One of the more important problems concerning the feasibility of using the OF_2-B_2H_6 propellant system is the evaluation of the extent and nature of the hazard arising if either or both of these toxic materials were liberated into the atmosphere. The chief concern in this discussion is the possible amount of the toxic material to which plants, animals, or man may be exposed. Threshold Limit Values (TLV) and Emergency Exposure Limits (EEL) published by the ACGIH provide the biomedical criterion for estimating the degree of exposure which may be tolerated. Judgments on tolerable release levels are then based on calculations to determine that these accepted values are not exceeded at particular locations or at prescribed boundaries.

Table 2-7. Instrumentation Requirements

Range of Concentration Detected	-	0.01 - 100,000 ppm by volume OF_2 0.1 - 100,000 ppm by volume B_2H_6.
Accuracy	-	±10 percent of full scale or 25 percent of reading, whichever is less.
Selectivity OF_2	-	sensitive only to oxidizers with oxidation potential greater than F_2.
	-	not responsive to dust, moisture, O_2, N_2O_4 or cleaning agents.
B_2H_6	-	sensitive only to reducers with reduction potention less than B_2H_6.
	-	not responsive to dust, moisture, H_2, N_2H_4 or cleaning agents.
Sensitivity	-	0.01 ppm OF_2. 0.1 ppm B_2H_6.
Precision (repeatability)	-	±10 percent of reading.
Portability, if manual	-	weight - 5 lb or less exclusive or batteries.
	-	size - 0.25 cubic feet or less exclusive of batteries.
Ambient Conditions	-	not affected by, or compensated automatically for temperature, wind, and humidity changes.
	-	withstand KSC high humidity, temperature and salt atmosphere.
Response time	-	95 percent full scale in ten seconds.
Readout	-	remotely to 3,000 feet.
Construction	-	solid state electronics, explosion proof, sealed.

2.5.1 PERTURBATIONS TO THE SIMPLE DIFFUSION EQUATION. The basis for the calculations is a diffusion equation. This equation is essentially a formula based on a normal Gaussian - dome shaped probability distribution curve. The greater the spill the higher the dome, where height represents the probable density, or concentration of toxicant in our case. This density C is given by the following mathematical expression in two dimensions:

$$C(x) = \frac{1}{(2\pi)^{\frac{1}{2}}\sigma} e^{\frac{-(x-\bar{x})^2}{2\sigma^2}}$$

where $\bar{x}$ is the mean value and σ is the standard deviation. In diffusion equations, x is distance downwind and σ is a turbulance or diffusion parameter. This subject is treated in References 13 through 22, where various complications are discussed.

1. Winds

This simple picture is complicated by the fact that winds distort the mound so that essentially no toxicant is found upstream. The greatest concentration is still located at the source but the material is stretched out in one direction so that it flows downstream as a plume at approximately wind speed. The plume also fans out and the peak concentration decreases with distance. Figure 2-2 shows an idealized plume or toxic cloud from a tall smokestack, for example. Figure 2-3 is an idealized graphic relation between the distance X and the emitted concentrations C or source strengths. The $v_{1,2,3}$---- represent increasing wind speeds.

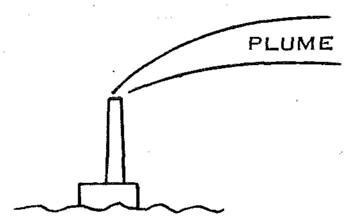


Figure 2-2. Idealized Plume or Toxic Cloud

2. Cross Winds and Eddies

Further distortions from the simple bell shape distribution are caused by turbulence and eddies which dilute the edges of the moving cloud. These perturbations are both small scale and large scale. The smaller eddies show up as vague indeterminate boundary gradients. Large scale turbulences are evidenced by meanderings of the entire plume.

Other complex circulation and shear wind patterns occur in a vertical direction where stratifications may exist. However, vertical perturbations manifest themselves more importantly as a result of temperature gradients.

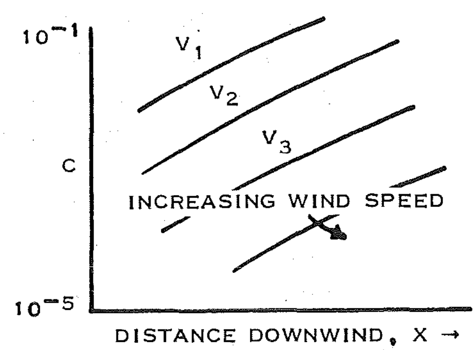


Figure 2-3. Increasing Wind Speeds

3. Temperature Effects

In the absence of heat interchange, air pressure decreases and volume increases with altitude so the temperature should decrease also according to the ideal gas laws. This temperature change with altitude is called a normal adiabatic lapse rate if the gradient follows the ideal gas laws. However, a variety of physical processes may cause the adiabatic lapse rate to vary in magnitude and even in sign at different levels of altitude so that superadiabatic or inversion conditions appear. If a rising mass of gas finds itself cooler than its surroundings, it will begin to descend. Lighter or warmer gas will continue to rise because of its buoyancy. Hence, the temperature and its vertical profile will regulate the dispersion of a toxicant.

4. Height of Source

It is commonly observed that a temperature inversion in which the gradient is positive, not negative with altitude, may completely change dispersion behavior. The spreading gas rather quickly equilibrates in temperature with its surroundings. If a higher layer is warmer than the gas it will not penetrate the layer but will level out. Lower levels will then contain higher concentrations than predicted from simple diffusion calculations.

If the source is elevated it is also possible that warm gas will not descend to pollute and fumigate the surface levels. In some cases a simplifying assumption such as initial vertical ascendency of hot gases may help in solving the problem.

5. Cryogenics

Complications are further compounded if the spill consists of cryogenic gases which may spread on the surface a considerable extent before they behave predictably. At NASA Plumbrook, liquid hydrogen was found to have no buoyancy. It descended so that a best fit was obtained by assuming it to be a ground source. After about 50 meters, less than 20 percent of the parameters are affected so that beyond this it is essentially a surface source. But this complication is minor compared with evaluation of the consequences of a fire which follows a fuel spill or a combined fuel and oxidant spill. Now the decrease in concentration of the propellants because of reaction requires a sink function in the concentration equation. The heat evaluation requires a buoyancy correction to the rising cloud.and if the reaction products are toxic, the calculation requires a new and different source term corrected for toxicity change and degree of reaction.

6. Sink Terms

In addition to reaction and fire which reduce the concentration, the dispersing propellants may also be absorbed on surfaces and vegetation, or dissolve and hydrolize in moisture or water. Terrain and ground cover are quite important in depleting surface concentrations. Most dispersion equations do not attempt to account for this depletion term thus leading to over predictions.

7. Puff Sources

In a situation involving a launch operation, extensive thought and engineering has entered the design so that leaks, spills, accidental corrosion, improper operations and insidious malfunctions have a low probability. Mishaps such as liftoff explosions do occur, however, and many happen instantaneously. Unfortunately for the prediction calculation, however, most forms of the diffusion equation were developed for continuous low level sources. The changes and alternations which must be adopted to allow one to apply the equations to instantaneous or puff releases, do not have a firm theoretical basis at this time.

2.5.2 DISPERSION PREDICTION EQUATIONS.

1. Sutton's Equation

The preceding discussion emphasizes the numerous considerations which must be provided as input to establishing a quantitative relation between the toxic concentration and the various parameters including meteorology source height, diffusion and wind transport, scavenging behavior, geography, distance, time and type of mishap. Sutton, in Reference 13, proposed an equation in 1953 for a ground level instantaneous point source:

$$\chi(x,y,z,t) = \frac{Q}{\pi^{3/2} C_x C_y C_z (\bar{u}t)^{\frac{3(2-n)}{2}}} \exp\left[-(\bar{u}t)^{n-2}\left(\frac{x^2}{C_x^2}+\frac{y^2}{C_y^2}+\frac{z^2}{C_z^2}\right)\right]$$

where

Q	= quantity of contaminant
$\chi(x,y,z,t)$	= concentration of contaminants as a function of time and location
C_x, C_y, C_z	= vertical diffusion coefficient
$\bar{u}$	= average wind velocity
t	= time since release
n	= Sutton's stability parameter.

This equation described the dispersion reasonably well but is unreliable because C_x, C_y, C_z and n vary with wind and weather.

2. The Ocean Breeze and Dry Gulch Diffusion Equation

Sutton's equation proved inadequate to accommodate the range safety concepts which were strange to many personnel at Titan missile launch sites. Hence, a program was undertaken to provide range safety officials and meteorological officers with an operationally useful computer system for obtaining data and making predictions regarding the potential of the atmosphere for diffusing and diluting pollutants. Data were obtained by measuring dosages of ground level emissions of fluorescent zinc sulfide particles under various weather conditions at Cape Canaveral (Project Ocean Breeze) and Vandenberg Air Force Base (project Dry Gulch). The prediction equation was developed by resorting to empirical and statistical methods.

Three meteorological parameters had been found important for characterizing the rate of low level atmospheric diffusion. These were wind speed, μ, which measures plume "stretch"; standard deviation of wind direction fluctuations, $\sigma(\theta)$, usually for 15 second intervals, a measure of horizontal rate of mixing; and vertical temperature gradient, ΔT, a measure of vertical rate of mixing. To characterize a spill one must know in addition the amount of material released per unit time Q (the source strength), the peak concentration, C_p, and the downwind distance, X. Regression analyses were then made to embrace all valid data for all probable meteorological conditions at both Cape Kennedy and Vandenberg AFB, and a third experiment, Project Prairie Grass. The final diffusion prediction equation chosen for the high probability, high confidence levels and good fit with the data then became, from Reference 17:

$$\frac{C_p}{Q} = 0.00211X^{-1.96} \times \sigma(\theta)^{-0.506} \times (\Delta T + 10)^{4.33}$$

where

C_p/Q = toxic concentration, gm/m^3/emission rate, gm/sec

X = downwind travel distance in meters

$\sigma(\theta)$ = standard deviation of wind direction in degrees azimuth

ΔT = temperature difference between 54 and 6 ft in °F.

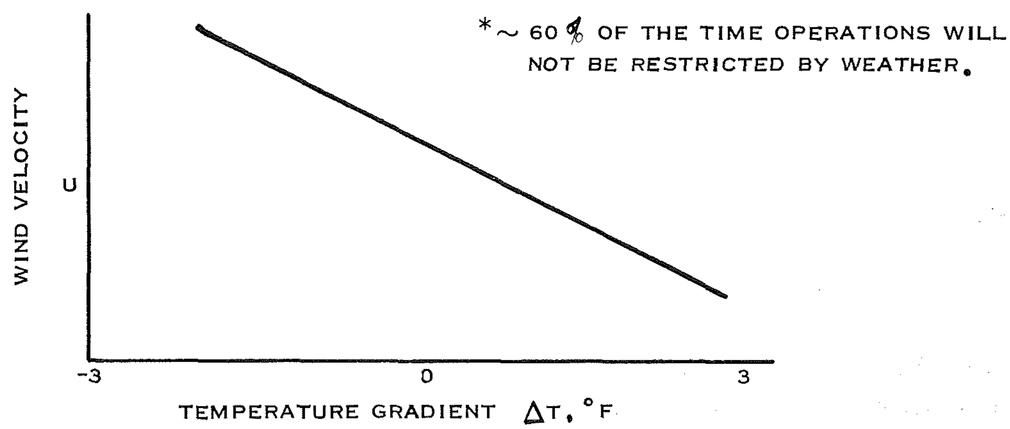
At KSC/AFETR, Titan operations including tanking and launch are restricted by Range Safety personnel based on computer analysis of this Ocean Breeze equation with meteorological data such as ΔT automatically measured at the site and fed into the computer. This equation is strictly applicable to ground level sources of about 10 to 60 minutes duration out to distances of five to ten miles. Different relationships apply to downwind diffusion by elevated, instantaneous puffs, line sources and cryogenic or reacting propellants. For example, one may be expected to be exposed to higher concentrations from the cloud of a puff release than from a plume wafting by for ten to thirty minutes.

This is important when "ceiling" values must not be exceeded in order to avoid irreversible tissue damage.

Elevated sources originating from hot clouds of reacting propellants or releases above ground also generate different toxic levels. Except for personnel in the vicinity of a launch pad station, a source originating above can diffuse through the atmosphere before it reaches the ground. This provides more time for protective measures as well as lower concentrations at the ground. This advantage disappears at extended downwind distances except when stability conditions allow the pollutant to travel parallel to the ground in stratified sheets until mixing breaks them up.

2.5.3 SAMPLE CALCULATIONS. It is of interest to determine the exclusion distances of the propellants even though the release mode and meteorological parameters cannot be specified for a particular episode. Limiting values, however, may be estimated if reasonable basic assumptions are made.

Operations can be restricted by meteorological conditions. Examining the data in Reference 17 which is summarized in Figure 2-4, it can be seen that the air is stable at night with a ΔT of 0°F or even an inversion layer, so tanking toxic propellants at night is generally forbidden. An unstable ΔT such as minus three degrees occurs frequently before noon, therefore this time would be scheduled for tanking, because any vapor cloud would rise rapidly away from personnel at ground level. A strong breeze tends to increase atmospheric instability, which favors dispersion.



	UNSTABLE	MOD. UNSTABLE	MOD. STABLE	STABLE
TEMPERATURE GRADIENT	≤ -3°F	-3°F ≤ 0°F	≥ 0°F ≤ 3°F	>3°F
FREQUENCY %	2*	58*	16	----

Figure 2-4. Ocean Breeze Stability Classifications

First, we may assume that a large spill occurs, at Cape Kennedy, under reasonably unstable conditions because these are prevalent there in the daytime. Operations would otherwise be secured, held up, or postponed because of the possible hazard. Let us assume a moderately unstable condition, $\Delta T = -3$ and a σ for wind fluctuations of eight degrees which is reasonably frequent at Cape Kennedy. The worst case for a toxic spill is the loss of all the OF_2 with no fire. Any reaction which is sure to occur if the fuel also spills can only reduce the hazard because the products are so much less toxic than the propellants. Let us further assume that the release is made instantaneously. Within this context we may assume that all the material will evaporate into the atmosphere within 120 seconds. (Evidence to support this evaporation time is reported in Subsection 2.5.4.) The 1,870 pounds of OF_2 at 32°F in the form of a sphere would be less than 15 feet diameter, and would generally blow past a point in two seconds in an eight knot wind. Our data now is as follows if we assume that our exclusion distance is two miles or 3,220 meters for Complex 41.

$$X = 3,220 \text{ meters}$$

$$Q = \frac{1,870 \times 453\text{g}}{120 \text{ sec}} = 7,058 \text{ gm/sec}$$

$$\sigma(\theta) = 8°$$

$$\Delta T = -3°\text{F}$$

Using the Ocean Breeze prediction equation, the concentration at the limit, C_p, is given by

$$C_p = Q \times 0.00211\ (3,220)^{-1.96} \times (10-3)^{4.33} \times 8^{-0.506}$$

$$= 7,058 \times 2.1 \times 10^{-3} \times 1.332 \times 10^{-7} \times 4.563 \times 10^{3} \times 0.3491$$

$$C_p = 0.00315 \text{ g/meter}^3$$

Using 54 as the molecular weight of OF_2, then

$$\text{ppm} = 0.00315 \times \frac{24,040}{54} = 1.4 \text{ ppm}$$

This value is about three times the recommended EEL for 10 minutes. Because of the probability and confidence limits, great discretion on the part of the Safety Officer would be required in this situation to decide whether such a release were tolerable. The effect of varying the standard deviation of wind direction to one degree and 25 degrees is to change the value of $\sigma(\theta)$ from 0.3491 to one and two respectively. This will change the result by a factor of three greater or 1/5 smaller (4.0 and ~ 0.3 ppm). Rather extreme but reasonable changes of ΔT from -3°F, to 0°F and -6°F change the term $(\Delta T + 10)^{4.33}$ from 4.563×10^3 to 2.71×10^4 and 4.05×10^2. The result then comes out six-fold higher and about one-tenth as high. The extreme possibilities from combinations are 15 and 0.07 ppm. The lower value is tolerable even on a continuous exposure basis, but the upper value probably represents fatal exposure.

If EEL values for NO_2 or N_2O_4 are used to determine a similar distance for Titan III oxidant we must use 20 ppm for the 30 minute EEL value and 1000 lb/minute or 7550 gm/sec for the source strength. This is an official value. Solving for X as before gives a distance of 933 meters or 3060 ft. This is less than the restriction imposed by the OF_2. However at the rate of 1000 lb/min it would take several hours for the N_2O_4 to dissipate if no reaction occurred. The exposure limit for a 30 minute duration would then be exceeded. Therefore, for the large quantities of non-cryogenic propellants in a Titan, the emergency limit may be taken as the same as the steady limit, TLV. While OF_2 is considered 100 times as toxic as N_2O_4, the proposed spacecraft uses more than 100 times less propellant than a Titan booster.

The actual exclusion distances and operating restrictions are not as tightly interpreted as these calculations tend to indicate. The launch pads are actually fairly remote from inhabited areas and measures for evacuation are part of the mode of operation and are relatively simple to accomplish. The extent to which restrictions are imposed also depend on the time of the day and on meteorological conditions. Operations during early morning hours require further distances of restricted access. However, operation is permitted 90 to 95 percent of the times during daylight hours. The weather conditions would have to be very severe, indeed, such as the presence of thunderstorms or positive temperature lapse rates, to halt operations completely. For launch operations the exclusion distance is 7,000 ft from toxicity considerations and 8,000 ft for blast hazard. However, conditions may require 16,000 ft for restrictions depending on the weather. The Range Safety Officer prescribes the limits as a result of real time computer solutions of the diffusion equation.

2.5.4 LN_2 SPILL TEST. The time for evaporation of a propellant spill leads to Source Strength Q or "Emission Rate" data which is necessary to estimate Exclusion Distance. A literature search failed to disclose any pertinent OF_2 or B_2H_6 spill information, and related data for oxygen, nitrogen and FLOX spills does not give us the required information, i.e.: what is the fastest boiloff time for a cryogen spilled under credible occurrence conditions? Most of the test work in the literature, including Convair's FLOX spills in 1965, relates to controlled spills in confined basins and does not apply to actual conditions of worse spills. In order to determine evaporation rates of OF_2 and B_2H_6 without incurring high test costs and safety hazards or the uncertainties of purely analytical work, an LN_2 spill test was run 28 August 1969 to first determine LN_2 boiloff rates empirically, then to correlate the results to space storable propellants.

The tests showed that a 50 gallon cryogenic spill on an ambient concrete pad about 25 feet square will totally evaporate in one to two minutes, perhaps 90 percent evaporated in 45 seconds. For low temperature cryogens, the time is nearer one minute; with higher temperature cryogens such as oxygen difluoride and diborane, the time is closer to two minutes. For larger spills such as might be experienced with the space storable propellant module (150 gallons), evaporation time for OF_2 or B_2H_6 would still be about two minutes, provided the spill area was approximately three times the test area, giving approximately the same cryogen film thickness. The evaporation times derived are "ball park" figures, but are on the fast side. Actual spills will usually take longer to evaporate because of uneven surfaces, depressions, puddling and containing structures. This test is documented in Reference 23.

2.5.5 RECOMMENDED DIFFUSION STUDIES. Because of the marginal safety under some common weather conditions, it seems advisable to undertake additional work to place the toxicity limits and the problem of diffusion of elevated, puff sources of cryogenic propellants on a firmer theoretical and experimental foundation. Sufficient data exist which allow limited predictions and evaluations. However the relative effect of OF_2 is not known.

1. Objective of Diffusion Studies

The objectives of a complete program would include the following:

a. Determine the Effect of Altitude and Elevation of the Source

(1) Source strength from a tank rupture.

(2) Propellant line failure.

(3) Destruct action.

(4) Fall back or on-pad failure.

b. Determine Experimentally Evaporation and/or Reaction Rates

(1) Cold spill on concrete, sand, asphalt, water: Sample to determine amount reacted and amount entering the atmosphere.

(2) Hot spill with both propellants under same conditions.

(3) Determine amount of propellant versus:

u Temperature at various heights above spill surface
w Materials
x Time
y Meteorological conditions
z Various conditions of ΔT, $\sigma(\theta)$, $\bar{u}$, h

c. Determine efficiency of water spray and water deluge on spills of various sizes.

d. Measure the vapor cloud, its rate of rise and rate of expansion under various humidity and unstable and stable meteorology conditions.

e. Determine base line data for measuring the effect of fluorine and of boron on soil, water and flora of different types, with run off and plant intake.

f. Determine meteorology especially to 1,000 feet, but also to 5-10,000 feet altitude, including wind velocity and direction, temperature, and humitity.

2. Experiments to Determine OF_2 Diffusion Properties

Experiments should be similar to the FLOX diffusion program successfully completed by Convair under NASA Contract NAS3-3245. The final report on this program, NASA CR-54926, Reference 12, describes tests for determining downwind dosages, cloud behavior, plume trajectories and evaporation rates from simulated spills. A similar plan may be used for OF_2. The objectives of the FLOX program were to determine the factors which influence the diffusion of fluorine and hydrogen fluoride in the atmosphere. Accidental and intentional releases were simulated and the following factors were studied:

a. Diffusion of fluorine and hydrogen fluoride into the atmosphere as a result of combustive and non-combustive spills.

b. Methods of spill control using water charcoal and containment.

c. Measurement of overpressures developed by a reaction.

d. Deposition of fluorides on the ground surface.

e. Measurement of fluorine and hydrogen fluoride concentrations on the surface out to five miles from the release point.

f. Quantity limits on fluorine use at the Sycamore Canyon Test Site.

The above program was accomplished by carrying-out and analyzing the results of the following type experiments:

a. Cold Source Tests.-These tests simulated a spill in the absence of fuel. Among the objectives of these tests were as follows:

(1) Determine the evaporation rate of the cryogenic propellant from various containing areas.

(2) Determine the effect of a cold plume from an evaporating surface on natural diffusion.

(3) Determine the effectiveness of water fog in controlling and suppressing the down-wind concentrations of fluorine from a non-combustive spill.

(4) Correlate data with visual results, instrument measurements and tracer diffusion.

b. Hot Source Tests.-These tests simulated a catastrophic spill of oxidiant in the presence of fuel. Among the objectives of the hot spill tests were the following:

(1) Determine the trajectory of the hot cloud produced by the combustive reaction.

(2) Measure the blast characteristics of the reaction.

(3) Determine the cloud size, trajectory and rate of motion as a function of heat release, cloud temperature, and meteorological conditions.

(4) Correlate tracer dosage measurements with field measurements of fluorine and hydrogen fluoride.

(5) Correlate results of cloud measurements with tracer material injected into the cloud.

(6) Observe facility damage.

The following types of experiments are suggested to supplement existing data and to establish a sound basis for the safe utilization of cryogenic OF_2 under conditions of abort or elevated source.

a. OF_2 and Tracer Releases from Altitude

(1) Tethered balloons (Figure 2-5) are relatively cheap and can lift over 1,000 pounds. They allow spills from accurately predetermined altitudes, are mobile and can obtain meteorological data during ascent.

(2) Make drops of OF_2 under normal lapse and under inversion conditions from 200, 500 and 1,500 feet altitude.

(3) Sample according to the three dimensional profile suggested in Figure 2-5. Obtain a three-dimensional picture of the concentration location and size of the gas cloud.

(4) Correlate data between ground release and altitude releases for a fit into a modified wind equation.

b. Biological Release Tests. These tests will serve as a biological dosimeter in conjunction with chemical detectors to assess fall-out dangers from OF_2.

(1) Place mice at each chemical collector and maintain until all effects and mortality from exposure have been observed.

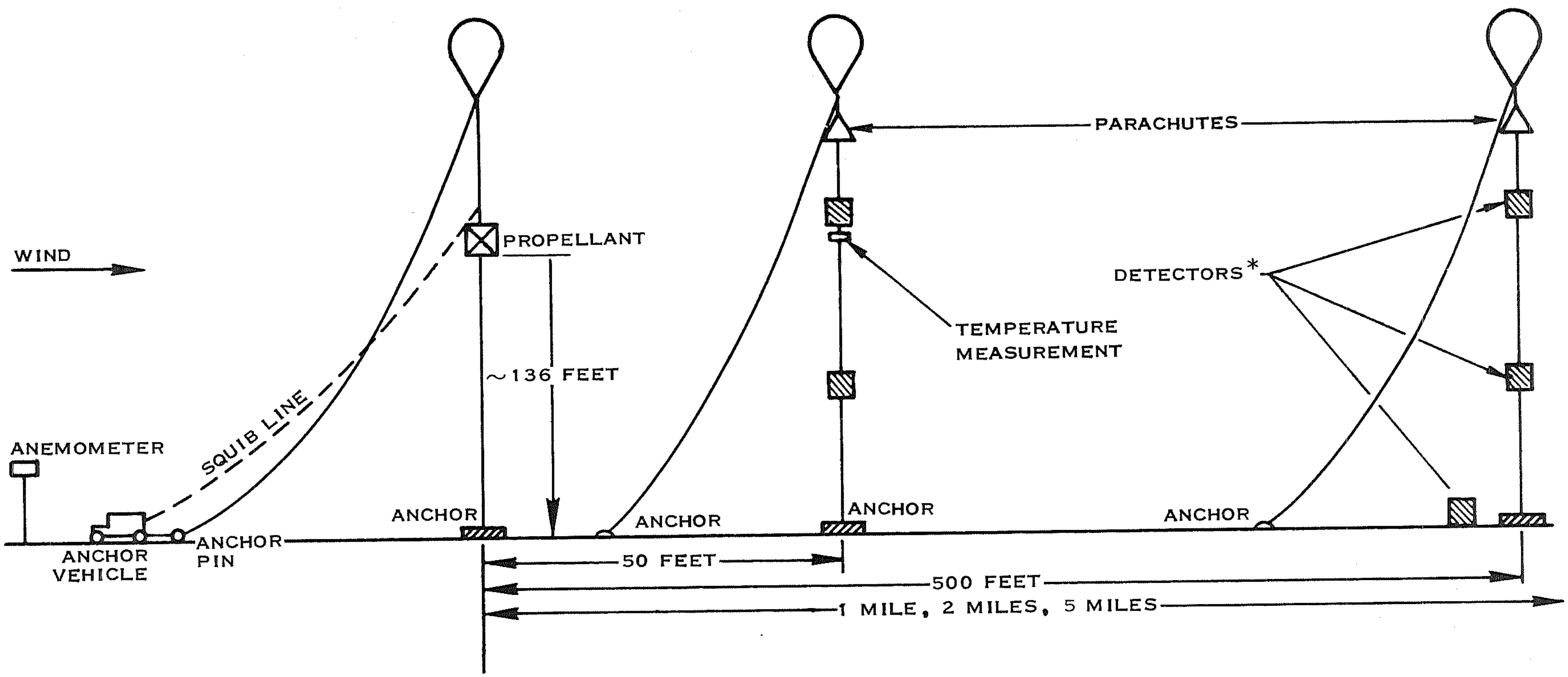
(2) Determine LD exposure time and concentration for the mice.

(3) Plot hazard in terms of mortality versus distance and direction of drop. Compare with total exposure determined instrumentally.

c. Hydrolysis Tests. These tests will determine the rate at which OF_2 is converted by moisture to HF which is one to two (depending on time) orders of magnitude less toxic:

(1) Make a cold spill with a simulated quantity of OF_2 and apply water fog. Simultaneously diffuse tracer material.

(2) Compare with a similar cold spill made to determine evaporation rate.



*GROUND DETECTORS SPREAD 45° FROM NOMINAL DOWNWIND.

Figure 2-5. Balloon-Borne Propellant Release

(3) Measure HF and OF_2 concentrations on down-wind radii.

(4) Correlate change in tracer concentration with changes in HF and OF_2 concentrations.

d. Reaction Delay Tests. These tests will determine the duration of the induction period, if any, which occurs when OF_2 reacts with water and spacecraft components:

(1) Inject OF_2 onto water. Measure ignition delay on photographic record.

(2) Inject OF_2 onto metals, paint, plastic, and insulation materials. Determine speed, extent and nature of reaction.

(3) Determine if apparently unaffected materials have absorbed OF_2 and become shock or temperature sensitive.

2.6 OPERATIONAL RESTRICTIONS

Introduction of oxygen difluoride and diborane as future spacecraft propellants at KSC/AFETR appears feasible and acceptable at this time. Emergency tolerance limits for these two propellants should be relaxed and detection equipment will have to be developed that is sensitive, reliable in the Florida environment, and discriminative. Apart from these two major items, the use of OF_2/B_2H_6 at the cape does not appear to cause undue concern at NASA HQ, the Air Force Office of Missile Safety, or the Titan ITL Complex. Most of the personnel directly involved in operations or safety agreed that the situation will probably evolve as a localized problem of handling and safety because of the small propellant quantities concerned.

The basic prelaunch requirements are defined in Reference 24, AFETR Range Safety Manual, including responsibilities of PAA Pad Safety, Directorate of Bioastronautics ETX, Missile Safety Division ETDM, and the Launch Agency (NASA-ULO). When toxic propellants are involved, "The Launch Agency will submit to ETX and ETDM an evaluation of the possible extent of the downwind hazard ---- including source strengths from a spill of a maximum probable amount of propellant------". In order to get an estimate of the operational restrictions which may be expected, an operational analysis was made to determine the maximum toxic release that should reasonably be expected at the various locations where the propellants may exist from storage through launch. The oxidizer provides the worst case since it has the lower Emergency Exposure Limit (EEL = 0.2 ppm for 30 minutes), and the larger quantity (2,000 pounds). Catastrophic incidents with a fluorinated oxidizer are more likely to happen under dynamic conditions like filling. Such operations can be restricted to favorable weather conditions and times of day.

Table 2-8 lists several types of catastrophic propellant losses and compares the risk of occurrence in various locations from storage to launch. From the point of view of

Table 2-8. Catastrophic Propellant Releases

Type of Catastrophe	Risk of Occurrence at:						
	Propel Storage Area Note #1	ESF (Wet) Note #2	Caravan (Wet)	Complex 41			Launch
				Erection	Standby, Wet Note #3	Tanking Note #4	
1. OF_2 reaction burns through tank wall or line and releases entire load = sudden cold release	0	Moderate	Some	Some	Negligible	High	Some
2. Dump Propellant: Valve malfunction of operator error. = steady cold release	0	Some	0	0	More from "tweaking"	Some	0
3. Fire starts from OF_2 leak into foam or spacecraft electrical malfunction and causes rupture of either or both propellant tanks	0	Moderate	Low	Low	More	Moderate	Low
4. Tank rupture from handling accident, puncture, dropped spacecraft, vehicle impact.	Negligible	Some	Some	More	0	0	Some

NOTES:

1. Storage is either in an ICC approved trailer or a permanently installed dewar.
2. At the ESF building, exhaust into a vapor disposal unit is feasible.
3. During standby at Complex 41, the propellant is 136 feet above the ground which minimizes danger to personnel at ground level.
4. Tanking at Complex 41 assumes the Propulsion Module was tested but not finally tanked at the ESF.

hazard to personnel from toxicity, a "cold" spill is worse than a "hot" release in which the heat of reaction or burning drives the toxic material up into the atmosphere while consuming some of the propellant. A cold vapor cloud may hug the ground and drift downwind. The worst case, then, is a sudden cold release of the entire OF_2 load of 2,000 pounds. We do not believe that such a major release of OF_2 would occur: spacecraft design, procedures, and trained personnel are combined to meticulously perform many delicate, sensitive and demanding steps in prelaunch operations. Nevertheless, AFETR Range Safety requirements dictate that failure analysis provide data on the worst possible catastrophe as a design limit.

The most toxic release would occur if a fluoride reaction burned through the oxidizer system allowing a sudden cold release of all the propellant. Burn throughs should occur during passivation or initial loading, if at all, so that only a limited amount of vapor would escape. There is only a remote possibility that vibrations or shocks to a loaded propulsion module could trigger a reaction. Moisture introduced by pressurization or purge will initiate a reaction. It is unlikely, but still possible, that this could occur any time during or after OF_2 loading.

A similar cold release could conceivably occur from a valve malfunction or operator error. Spacecraft design normally has built-in safeguards against this: redundant closures or disarming capability. Still, operator errors can occur, such as "tweaking" during checkouts. This probability is highest at the launch pad where complete launch control electrical systems are installed.

A fire could start in the spacecraft from an OF_2 leak, electrical malfunction, or a booster source. Flammable materials including foam should not be used in the spacecraft, but still fires can occur. One or both propellant tanks could be penetrated leading to a large instantaneous hot release that would cause the toxic material to rise.

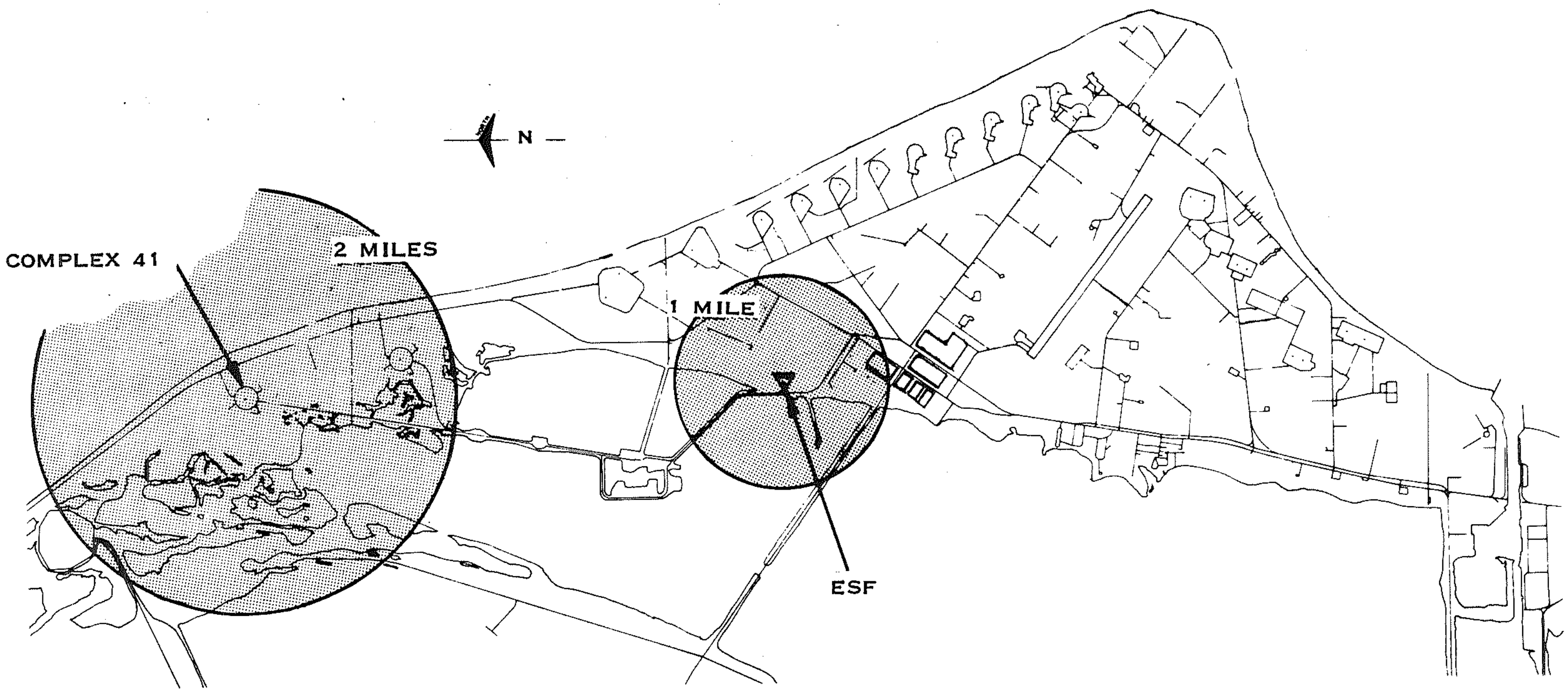
There is almost no chance the Propulsion Module tank could fail from a handling accident, puncture, dropped spacecraft, or vehicle impact from launch abort. Overpressure is prevented by emergency relief valves and burst diaphragms, GSE or airborne. These spacecraft tanks are quite rugged with about 400 psi operating pressure. The shroud protects the spacecraft once encapsulated.

Taking into account all the safety aspects and worst possible types of catastrophic toxic propellant releases, it is theorized that KSC/ETR Range Safety will impose the following reasonable operational restrictions on a propulsion module with about 3,000 pounds of space storable propellants:

1. <u>Estimated Operational Restrictions during Passivation and Tanking at ESF</u>

    a. Road blocks out one mile (close parts of Titan III Road, Cape Road and NASA East Causeway to Merritt Island). See Figure 2-6.

    b. Alert Cafeteria No. 2, Hanger "U", and VIB.



	AT ESF-PL	AT COMPLEX 41
ROAD BLOCK RADIUS	1 MILE	2 MILES
ALERT AREAS	INDUSTRIAL AREA VIB	SATURN COMPLEX 39
WIND DIRECTION	SW OR NE	ANY; PREFER WEST
AIR STABILITY ΔT	VERY UNSTABLE, −3 °F	UNSTABLE, NEGATIVE
% DAYS	50% MID-MORNINGS	90 % DAYTIMES

Figure 2-6. Operational Restrictions During Passivation and Tanking

c. Operate with SW or NE wind fluctuating eight degrees; shut down if from N or NW.

d. $\Delta T = -2$ or $-3°F$ or more; i.e., very unstable atmosphere.

e. Do not operate at night (this may allow operation in the morning 50 percent of the year).

2. Passivation and Tanking at Complex 41

   a. Road blocks out two miles (close Cape Road).

   b. Alert Complex 39, clear Complex 40, alert VIB.

   c. Operate with wind from any direction, fluctuating as little as one degree, preferably westerly.

   d. ΔT negative, as $-1°F$; i.e., slightly unstable atmosphere.

   e. Do not operate at night (this may allow operation in the daytime 90 percent of the year).

During other periods when no propulsion system functions are being done, workmen should have access directly to the spacecraft, in limited numbers of pairs, while fire and leak detectors are automatically and continually monitoring.

From the wide range of safety aspects in handling a space storable propulsion module at KSC, three conclusions are drawn:

1. Propellant loading can be safely performed at either the ESF or Complex 41, but with tighter meteorological constraints at the ESF. Weather data tabulated in Reference 17 indicate that sufficiently unstable air normally occurs at KSC about half the days during the mornings. These added restrictions are due to the proximity of the ESF to Base Cafeteria No. 2, and the requirement to transport a wet spacecraft about five miles to Complex 41.

2. Space storable propellant safety problems are basically the same as those of the Titan. The oxidizer causes the maximum hazard whether it is FLOX, OF_2 or N_2O_4.

3. The state of the art is reached or exceeded in measuring and predicting the downwind concentration from a toxic release. Development is recommended for selective, sensitive, remote readout instrumentation and studies to firm up the theoretical and empirical foundation for toxicity limits and atmospheric diffusion of elevated, puff sources of cryogenic propellants.

3

PROPELLANT STORAGE

Space storable propellants, including diborane and oxygen difluoride, can be brought into the Cape in special containers with an ICC permit. There are several possible locations and modes of storage. Convair recommends utilizing a new 800-pound diborane dewar, and leasing the Allied 5,000-pound trailer for storage adjacent to the ESF or Complex 41. Sections 3 through 6 present conceptual designs of the GSE and facilities. Propellant storage containers, propellant thermal control units and site piping arrangements are defined in some detail. Several concepts of vapor disposal units are discussed. It can be seen that the equipment required for prelaunch operations with space storable propellants is not only feasible but also may be relatively simple and dependable.

3.1 DIBORANE (B_2H_6) MOBILE TRANSPORT UNIT

To date, diborane has been shipped in 40-pound containers, dry-iced in wooden crates. To use quantities in excess of 40 pounds at a time, the diborane is transferred to a storage tank, then piped to the using unit. Shipment is covered by ICC special permit 970 from Callery, Pennsylvania. A 200-pound, skid-mounted dry-iced shipping container is presently under development and is scheduled for availability in 1970. An inherent disadvantage of the solid-CO_2 cooled shipping container is the B_2H_6 vapor pressure. At solid-CO_2 storage temperature, diborane has a vapor pressure of 29 psia, making storage more hazardous than with subcooled, helium-blanketed liquids. Periodic replenishment of the dry ice is required.

The small capacities of the 40- and 200-pound containers are also disadvantageous for this program since they cannot be used to load or drain the propulsion module (625-pound propellant load) directly. Incremental loading and draining is cumbersome and dangerous. A separate storage facility for module loading and draining would therefore be required, which is undesirable from two standpoints: extra handling is required in transferring propellant from small shipping containers to the storage tank, and a separate drain unit of at least 700-pound capacity would be required for disposal of contaminated fuel, or for transfer of fuel from one storage tank to another.

To reduce the hazards involved in handling diborane in the quanitities required for the Space Storable Propellant Module, it would be advantageous to develop a new multi-purpose diborane dewar, a road transport unit of 800-pound (32-cu. ft.) capacity. Development of this dewar appears justifiable technically, economically, and from an overall safety standpoint of reducing the number of times the diborane must be handled. It can be used not only as the transport unit from the chemical production facility to the Kennedy Space Center, but can be parked in a toxic storage area at the Cape, obviating the need for a permanent stationary storage facility. When ready to load the propulsion module, the mobile dewar can be brought to the loading and weighing site - either the ESF or Complex 41 - to transfer fuel directly from dewar to propulsion module. Off-loading or draining of diborane would be from the propulsion module directly back to the transport dewar, and could be accomplished at the ESF, enroute to the launch complex, or at the pad.

Design requirements for the transport dewar should specify:

1. Subcooled and loss-free B_2H_6 storage.
2. Remotely operated redundant diborane valving plus manual emergency valves.
3. No electromechanical refrigeration.
4. No dependence on electrical power other than sensing.
5. No dependence on pneumatic power. Pneumatic valves to be installed in power failure system-safe mode.
6. Redundant pressure and level alarms.
7. Integral vacuum system for fill, drain, and vent line evacuation.
8. Integral helium purge system.
9. 30 day hold without servicing.
10. Inexpensive, readily-available consumables.
11. Design load shock factors of 3 g vertical, 2 g longitudinal, 1 g lateral.
12. 75 psi design operating pressure, 300 psi burst in B_2H_6 system.

Advantages to be gained by the use of the multi-purpose dewar can be summarized as follows:

1. Eliminates the repeated connecting and disconnecting of multiple shipping containers.
2. Eliminates middle-man handling from shipping containers to storage facility to Propulsion Module.
3. Eliminates design and installation cost of a fixed storage facility.
4. Eliminates design and fabrication cost of single-purpose drain tanks or liquid disposal units.
5. Permits transport of contaminated fuel to disposal area, if required.
6. Simplifies loading system requirements; long transfer lines from toxic propellant storage area to module loading location are not required.

7. Flexibility - provides storage, loading or draining at any appropriate location.

8. Provides immediate re-load capability, vis-a-vis draining to a disposal unit.

9. Provides minimum risk through minimum wetted systems, i.e., transport dewar, fill and drain lines, and module only.

A suggested design for the B_2H_6 multi-purpose dewar is shown in Figure 3-1. For simplicity, the vacuum and purge systems, fill and drain lines, and chassis have been omitted.

3.1.1 DESIGN FEATURES. Basically, the dewar consists of two refrigerant tanks enclosed in an outer vacuum shell insulated with 80-mesh evacuated perlite. The primary refrigerant tank holds liquid nitrogen, held at 165°R by 45 psig back-pressure relief valves. The secondary refrigerant tank holds tetrafluoromethane, CF_4 (Freon 14), as a thermal shield around the inner diborane tank, at any desired storage temperature from solid B_2H_6 at 165°R up to liquid at 280°R. (Freon 14 itself freezes at 160°R and has a normal boiling point of 260°R.)

In operation, a pressure controller compares the Freon 14 tank ullage pressure with the desired set point pressure (temperature), and opens or closes the LN_2 supply valve to the refrigerating coil in the Freon tank as required to maintain the set vapor pressure. The set point dial is calibrated in temperature units rather than pressure. At 250°R, the saturation temperature change is 3° per one pound vapor pressure change, allowing a probable temperature control accuracy of ±3°R.

Liquid nitrogen at 165°R is above the freezing point of Freon 14, allowing the Freon 14 to act as a passive liquid heat transfer media and thermal shield around the diborane tank. Liquid nitrogen flow is by gravity only for simplicity. A pump can be added to reduce line sizes. Heat of vaporization is absorbed in the Freon tank at about 100° ΔT, the gaseous nitrogen then superheating to 250°R as it passes to the ullage coil and vents back to the nitrogen tank vent line.

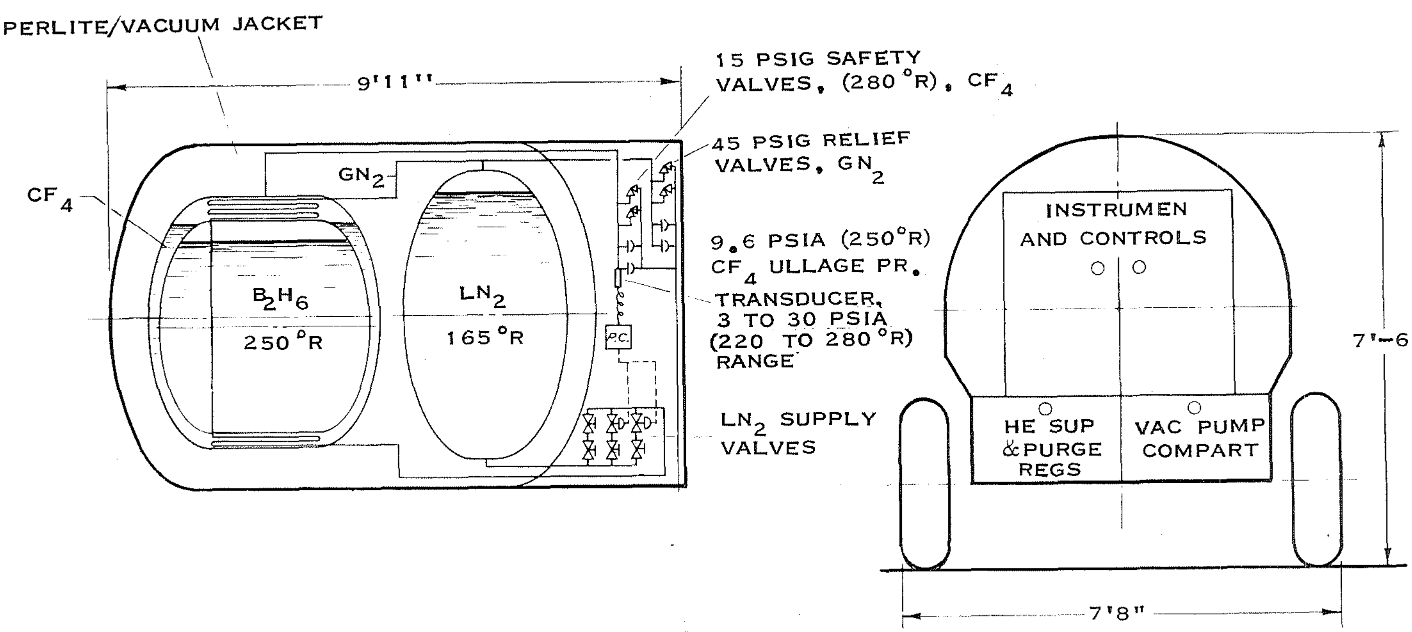
Choice of a passive secondary refrigerant system rather than direct LN_2 cooling is advisable for the following reasons:

1. It eliminates problems of localized fuel solidification in contact or proximity to low temperature nitrogen lines.

2. It provides simplified and more accurate temperature control than is possible with vapor expansion coil cooling.

3. It provides a liquid heat transfer medium at all times.

4. It provides a refrigeration reservoir in event of loss of LN_2 supply.



TANK	OUTER SHELL	CF_4	B_2H_6	LN_2
DIAMETER	72"	52"	44"	60"
LENGTH	101"	48"	44"	34"
BULKHEAD	2:1 ELL.	2:1 ELL.	2:1 ELL	2:1 ELL
TOTAL VOL. CU. FT.	209.7	48.34	32.26	39.27
ULLAGE VOL. CU. FT.	0 (PERLITE)	5.50	6.54	3.93
NET CONTENTS VOL. CU. FT.	122.0	10.48	25.72	35.34
NET CONTENTS VOL. GALS	–	79.4	192.4	264.3
TEMP., °R	–	250.0	250.0	165.0
DENSITY, LBS/ CU. FT.	8.7	103.9	31.1	46.1
WEIGHT, LBS	1062.0	1100.0	8000	1630.0
TANK MATERIAL	CARBON ST.	CRES	CRES	CRES
OPER. PRESS. PSIG	VAC.	15	100	45
WEIGHT, LBS	1550	160	195	310

TOTAL TANK + CONTENTS WEIGHT: ~6800 LBS

Figure 3-1. B_2H_6 Mobile Transport Dewar

LN_2 is chosen as the primary refrigerant because it is relatively inactive, non-toxic, readily available, and inexpensive. Properly constructed, the LN_2 boiloff loss will be approximately 7 to 8 gallons, or approximately 64 cents, per day. Hold time without resupply of LN_2: > 30 days.

Freon 14 is a natural choice for the passive refrigerant. It is the most chemically inactive of all the fluorocarbons (fluorinated methane), is non-toxic (U.L. group 6; no effects from 2 hour exposure in 20 percent concentrations in air) and physically and thermodynamically best suited for the LN_2/B_2H_6 temperature ranges. There is an initial cost of several thousand dollars for 80 gallons of Freon; there is no operating consumption.

Design of the dewar is dictated primarily by safety considerations to assure a controlled, loss-free storage of diborane regardless of system or component malfunction. Failure analysis indicates fail-safe operation, as follows:

1. If electrical or pneumatic power fails: LN_2 supply valves go open. Action option:
   a. Allow Freon to chill to 165°R, freezing the diborane.
   b. Use manual LN_2 supply valve to maintain proper temperature.
2. LN_2 supply valve sticks open: same as electrical power failure.
3. LN_2 supply valves (both) stick closed: open manual by-pass to control set temperature, or to freeze the diborane.
4. Pressure transducer/controller system signals low temperature, closing LN_2 valve: use manual by-pass control.
5. All LN_2 valves stick closed, Freon 14 high pressure alarm also fails, LN_2 line ruptures, or no one is present to take action: Freon 14 rises in pressure and in temperature to 280°R and is maintained there by boiloff relief valves set at 15 psig. Hold time without resupply of Freon: 30 days.
6. Freon relief valves both fail to open: rupture disk bursts, venting off inert Freon 14 gas, dropping Freon pressure to atmospheric and temperatures to 260°R. 30 day hold time without resupply of Freon.
7. LN_2 relief valves fail open, or fail closed and the rupture disk bursts: LN_2 pressure drops to atmospheric and temperature drops to 140°R. Temperature control continues normally, but localized solidification of Freon may occur. If LN_2 refrigerating coil is flooded, Freon 14 as well as diborane will solidify.

3.1.2 OPERATIONAL USE. Barring highway accident, sabotage, or failure to service the trailer every 30 days, the dewar will hold diborane indefinitely at the desired temperature without hazard.

If the mobile dewar is to be used for propulsion module loading at ground level only, then no particular design constraints exist other than those listed.

If the dewar is to be used on the ground to liquid-load a spacecraft already mated to the launch vehicle, then the diborane tank will have a 35 psi static head requirement in addition to the transfer pressure requirement. Seventy-five psi design working pressure is adequate.

If the dewar is to be elevated to spacecraft level for loading, then design constraints on physical size and weight are imposed. The existing freight elevator on the Titan Missile Service Tower has an 8 × 8 foot door, and will take a vehicle no more than 10 feet long weighing 12,000 pounds. Weight appears to be no problem. The preliminary design shown is sized to fit the MST freight elevator. If the dewar is unrestricted in size, roadability can be improved and the hold capability can also be increased, if desired.

In any case, two of the mobile dewars are required. One dewar would remain filled with diborane, on standby, to provide load capability in the event that fuel in the working dewar became contaminated, or had to be disposed of for other reasons. Unavailability of one dewar must also be considered, for servicing and repairs.

To provide drain capability at the launch pad, one dewar would be parked at the base of the umbilical tower, connected to the tower drain line. This is the same dewar used for loading at the loading facility, or for loading from ground level at the pad. If loading is to be done from an elevated dewar, however, then a third dewar is required, or the drain capability must be accepted as non-existent while the empty dewar is brought down from the service tower to ground level and connected to the drain line.

3.1.3 DIBORANE FREEZING CAPABILITY. As an emergency capability, the liquid nitrogen supply valve can be set open, flooding the refrigerating coil in the Freon 14 tank and dropping the liquid Freon temperature to 165°R, solidifying the diborane at 30° below its freezing point. This technique has been used by Rocketdyne to permit maintenance replacement of shutoff valves in a diborane system, with no vapor loss and with minimum risk. A helium blanket is maintained on the solid diborane during repairs. An analysis should be made of the real ground safety and spacecraft performance benefits, or liabilities, from freezing the fuel.

3.2 OXYGEN DIFLUORIDE, OF_2, STORAGE CONTAINERS

Oxygen difluoride in quantities greater than 1000 pounds can best be shipped in the 5,000 pound liquid fluorine transport trailer developed by Allied Chemical. Six of these units are in existence, and are designed specifically for either liquid fluorine or liquid oxygen-difluoride transport. The trailer, without tractor, has a length in excess of 29 feet, and has a gross weight of 26,000 pounds. The inner, or product tank, is designed for an internal working pressure of 70 psig. The inner tank is surrounded by a liquid nitrogen tank or thermal shield, vented to atmospheric pressure, which maintains the LF_2 or LOF_2 at -320°F. An outer perlite-filled vacuum shield reduces heat flux to an LN_2 boiloff rate good for 25 days without servicing. Without liquid nitrogen, a period of about 4 days is required to raise the product vapor pressure to tank working pressure. Subsequent product loss would be approximately 1.3 lb/hr of OF_2.

The rationale previously discussed for development of a triple-purpose diborane dewar (shipping, storing, and fill and drain) is also applicable to the use of the existing allied liquid fluorine transport trailer as a multi-purpose unit. The trailer is licensed for cross-country transport. It is available for lease or loan and can be used at the Kennedy Space Center for OF_2 storage and for propulsion module fill and drain. As with the diborane dewar, its use would eliminate need (and cost) of a permanent storage facility, would permit flexibility of storage location and loading location, and minimize propellant handling and the number of wetted systems involved. The unit is road-proven, safe and reliable, and requires no investment in design, fabrication or testing.

At 70 psig working pressure, the Allied trailer can be used to transfer -320°F LOF_2 to a maximum elevation of 90 feet. The trailer is therefore suitable for LOF_2 loading of the propulsion module at or near ground level, e.g., at the ESF Propellant Laboratory. It can also be used at the launch complex to load the module at an elevation of 130 to 140 feet, if a vapor transfer system is used.

The Allied trailer is far too large and heavy to be handled at the 12th or 13th level of the launch complex. If loading were to be required from these levels, a smaller, lighter dewar would have to be developed, consisting essentially of an inner 200 gallon OF_2 storage vessel surrounded by a concentric LN_2 tank or thermal shield, and an outer vacuum/perlite jacketed insulation shell. At Rocketdyne's Nevada facility, OF_2 is stored in a liquid-nitrogen-jacketed 500-gallon dewar which is actually a surplus Atlas weapon system LOX subcooler.

If a larger size propulsion module, safety, or program considerations dictate liquid loading at the launch complex, a new oxidizer dewar must be constructed. About 150 psi operating pressure would be the design point to lift OF_2 over 130 feet up the umbilical tower. This is likely to be the case on a FLOX/methane propulsion module.

3.3 POSSIBLE PROPELLANT STORAGE AREAS

At KSC/AFETR there are several possible propellant storage areas. Pan American Airways has usually provided spacecraft propellants from several storage areas alongside the Cape Road, and there are permanent propellant storage areas located at each launch site. As discussed below, storage adjacent to where the propulsion module is tanked is recommended, either at the ESF or Complex 41, to minimize moving the propellants around and to minimize the number of people who must be trained to handle them.

3.3.1 EXISTING KSC LIQUID PROPELLANT STORAGE AREA. This facility, managed by Pan American, is situated on the south side of the Cape Road, about 3 miles north of the South Gate entrance, Figure 3-2. Hydrogen peroxide is stored here, there is a propellant inspection lab, and a large parking area for transport trailers. The Cape Road is the main Kennedy Space Center artery, leading from the South Gate to the Industrial Center 5 miles to the north, and is well traveled at all times, with exceptionally heavy traffic at shift change. Traffic consists of military and civilian personnel, industrial traffic, and civilian visitors (tour buses).

Storage of both diborane and oxygen difluoride in separate areas at this location is feasible, provided that "storage" is understood to mean "parking" of cryogenic transport trailers. No permanent storage tanks should be considered here, which would involve transfer of propellants between trailers and storage tanks. Such handling would require safety procedures such as road blocks and evacuation of the area, and would interrupt Space Center operations.

Storage of propellants in this area has disadvantages with regard to the Space Storables Propulsion Module program. Another crew of people must be trained to handle the propellants. Hazard sensing systems, special water fog systems, etc., may be required in a new area remote from other propellant storage. Propulsion module loading operations would require transport of each propellant over the Cape Road and through the heart of the Industrial Complex, 4 miles to the Explosive Safe Facility or 10 miles to Complex 41, which are the two locations being considered for loading. A round trip from the storage area would be required for a transport trailer each time a propellant was loaded. For two spacecraft, two propellants, a minimum of four round trips would be required; training exercises and possible aborts could double or triple this number. Assuming these propellant trailers are ICC certified, they can use the Cape Road without blockages, but still the logistics are time consuming and subject to delays.

To minimize or eliminate these inconveniences, storage of propellants north of the industrial complex and within reasonable distance of the candidate loading sites seems to be indicated.

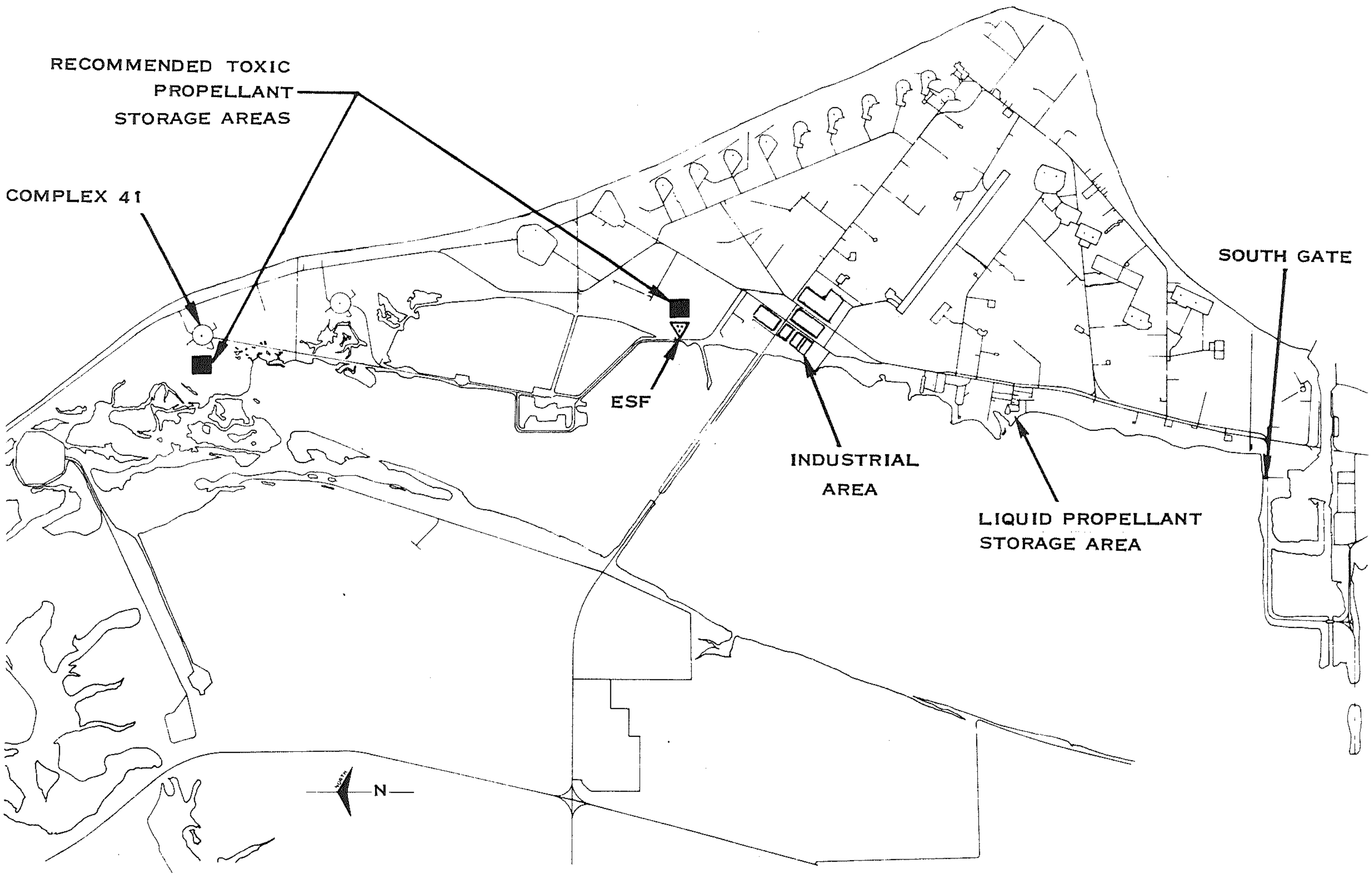


Figure 3-2. Kennedy Space Center

3.3.2 EXPLOSIVE SAFE FACILITY. If propulsion module loading is to be done at the ESF, a clear area exists just east of the facility (Figure 3-2) which can be used for toxic propellant storage. This area can be fenced and connected to the explosive safe area with a short fenced road. Storage of propellants in transport dewars here would be about as safe as at the KSC Liquid Propellant Storage Area, being further removed from arterial road traffic, but closer to the populated industrial area. Operations, however, are vastly simplified. ESF personnel can monitor the storage area. When loading operations are scheduled, there would be no escort or road block arrangements to be made, no travel on "public" KSC roads to interfere with other transportation activities, and no operational delays. Movement of the storage dewars from the storage area to the loading building would be under the direct observation and assistance of qualified ESF personnel familiar with these propellants and their handling.

3.3.3 PROPELLANT STORAGE AT COMPLEX 41. The discussion on propellant storage at the ESF applies equally well to storage at Complex 41, with a few minor differences. Areas both east and west of the launch complex are available for propellant storage, and are even further removed from road traffic and other base activities than storage at the ESF or Liquid Propellant Storage Area. Storage at the launch complex is advisable only if loading is to be done on a mated spacecraft. If loading is to be done only at the explosive safe area, then storage at the complex would complicate both operations and safety considerations.

Larger propulsion modules, such as FLOX/methane kick stages, will very likely dictate propellant storage at the launch site. Note, however, that one launch complex may be used for a variety of missions, utilizing different payload/propulsion modules, so it is undesirable to overcrowd the site with mission-peculiar hardware.

4

PROPELLANT THERMAL CONTROL

4.1 DESIGN REQUIREMENTS

Two basic requirements have been adhered to in the study of oxygen difluoride and diborane propulsion module thermal control:

1. Thermal control of the airborne tank propellants must be maintained between 210° and 280°R, with a targeted prelaunch propellant temperature of 220°R.
2. No vent, therefore propellant vapor condensation and recirculation systems with ground heat exchangers will not be considered.

The propellant thermal data used for this study is presented in Appendix B. Design of the thermal control system, if possible and practical, should meet the following objectives:

1. Non-toxic refrigerants.
2. Inexpensive, readily available consumables.
3. No electromechanical refrigeration, to avoid long term dependence on compressors, power supply, etc.
4. No dependence on electrical power other than sensing.
5. No dependence on pneumatic power. Pneumatic valves, if used, are to be installed in a power-failure system-safe mode.
6. Seven day thermal control capability without resupply.
7. Small size unit for mobility.

4.2 THERMAL CONTROL WITH COMMON BULKHEAD TANKS

Although spacecraft propellant tank configurations and insulation systems are necessarily dependent on space residency and mission objective factors, configurations which lend themselves to ground hold system concepts should be mentioned for possible application to future designs, particularly if they also possess desirable airborne characteristics. One such configuration is the common bulkhead tank. In comparison with multiple tank configurations, it has the advantage of highly efficient space utilization, greatly simplified engine propellant feed plumbing and valving, and a nearly constant lateral and axial c.g. From a ground hold refrigeration system standpoint, it also lends itself to remarkably simple and efficient thermal control of oxygen difluoride and diborane propellants.

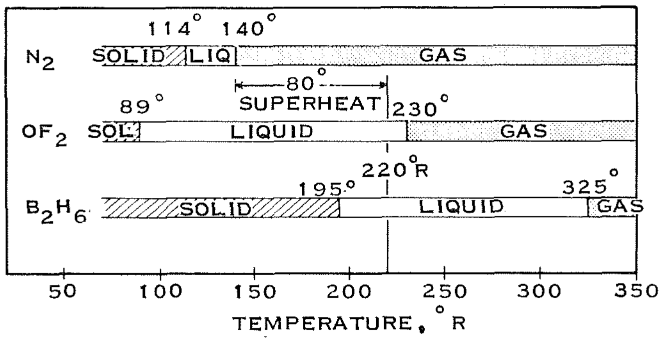


Figure 4-1. Temperature/Pressure Comparison of LN_2, OF_2 and B_2H_6

The freezing point of oxygen difluoride (Figure 4-1) is 89°R (-371°F), far below the normal atmospheric boiling point of liquid nitrogen, 140°R (-320°F). The liquid nitrogen can therefore be used as an inexpensive single-pass two-phase refrigerant to maintain the airborne OF_2 tank at any desired temperature above 140°R without danger of freezing the oxygen difluoride and inhibiting heat transfer. At a prelaunch OF_2 temperature of 220°R, the liquid nitrogen can boil at 140°R, providing an 80° liquid/liquid ΔT, and then superheat to 220°R if the gaseous boiloff is allowed to act as a thermal shield before escape. Diborane freezes at 195°R, therefore direct cooling with LN_2 at 140°R would cause local or total freezing.

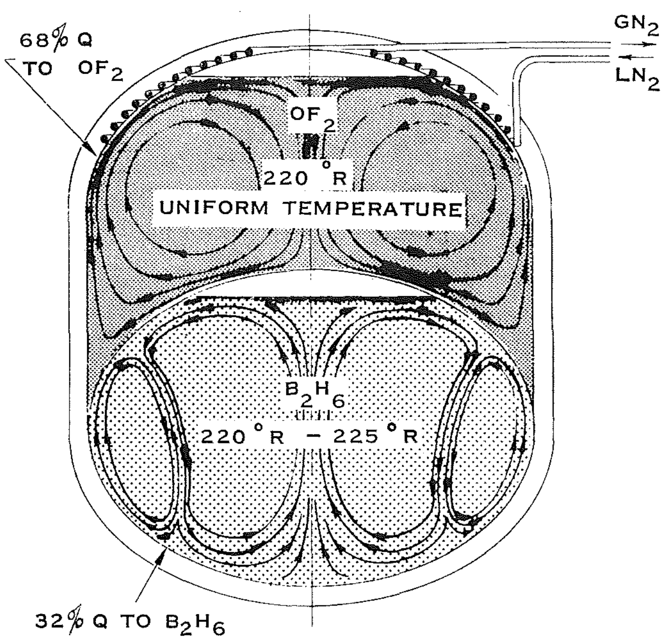


Figure 4-2. Single Refrigerant Thermal Control of Common Bulkhead Tank

A common bulkhead tank is shown in Figure 4-2, with the liquid nitrogen refrigeration heat exchanger coils bonded to the upper surface of the oxygen difluoride tank. With its greater wall area, approximately 2/3 of the total tank heat leak is into the OF_2 section. Heat transfer to the cooling coil is by OF_2 liquid convection/conduction through the tank wall, and by vapor condensation on the ullage wall. Ullage pressure sensing is used to control the liquid nitrogen input.

The B_2H_6 tank absorbs approximately 1/3 of the total heat leak. Heat is absorbed by the B_2H_6 at the bottom of the tank and transferred by natural convection currents at 2 to 5° ΔT to the common bulkhead and into the OF_2.

Stratification does not exist in this concept; heat input to the bottom and sides of the B_2H_6 tank, which is under helium pressurization, provides constant convection circulation without boiling. With the OF_2 at a saturation pressure of 10 psia, heat input to the bottom and sides of the tank provides boiling circulation at nearly constant temperature.

A simple, reliable ground hold refrigeration system for the common bulkhead tank is shown in Figure 4-3. An elevated storage tank supplies a positive head of liquid nitrogen to the spacecraft. The storage tank is vented to atmosphere and there is no dependence on a pressurization system for LN_2 supply. The supply valve to the spacecraft fails open (safe) on loss of pneumatic power or loss of electrical power to the pneumatic system. An emergency by-pass valve is provided if the remote controlled pneumatic valve should for some reason stick or freeze in the closed position.

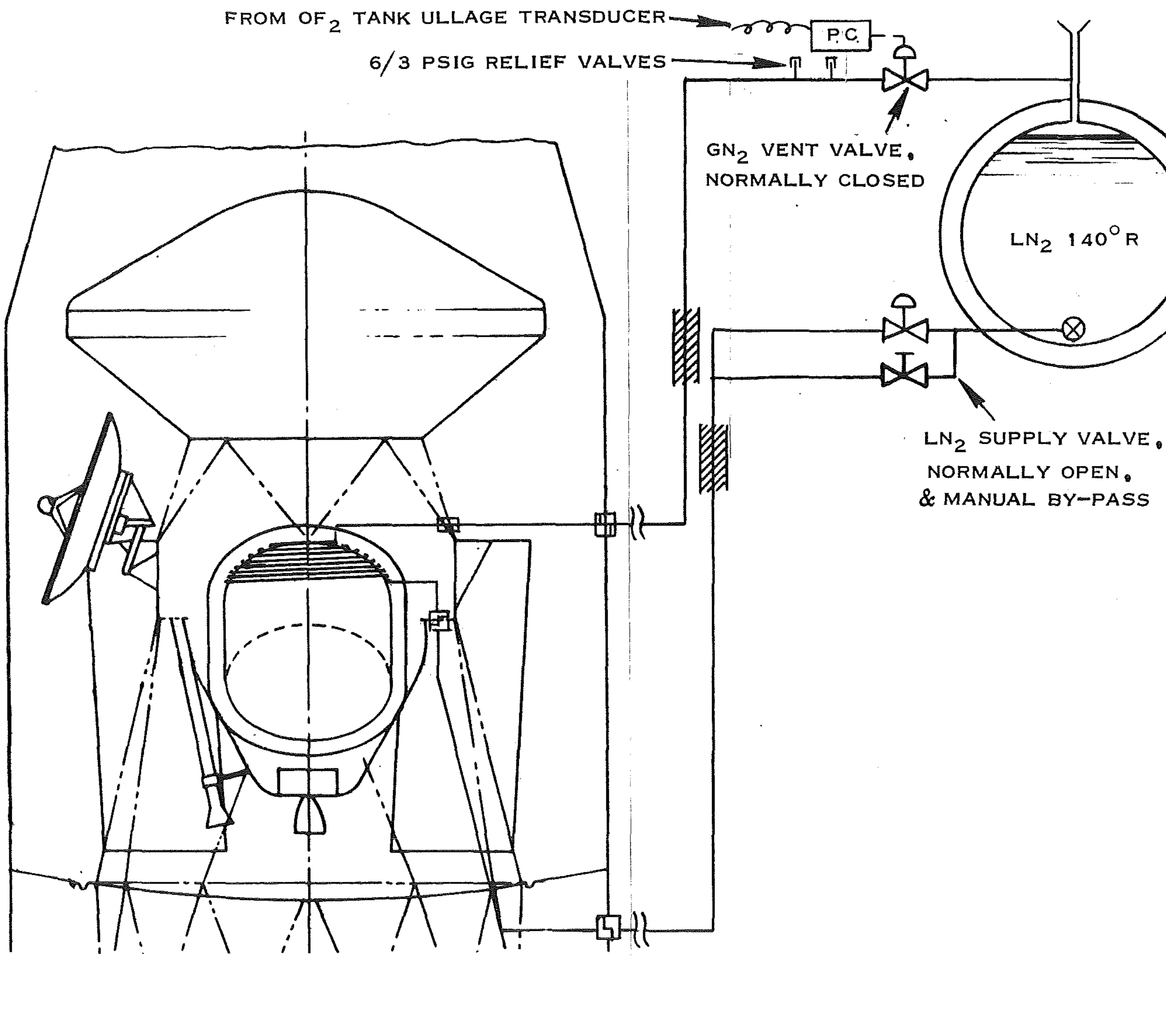


Figure 4-3. Propulsion Module Thermal Control with Common Bulkhead Tank

The vent side of the refrigeration line is controlled by a vent valve and pressure controller, activated by signal from an ullage pressure transducer in the OF_2 tank (using a pressure transducer, we feel, is more reliable than control by a liquid temperature transducer). A drop in the OF_2 liquid temperature and vapor pressure signals the pressure controller to close the GN_2 vent valve, driving the LN_2 level in the heat exchanger coils down. As the OF_2 liquid temperature and vapor pressure begin to rise, the ullage pressure transducer and pressure controller open the vent valve, allowing the LN_2 level to rise. Failure of the GN_2 vent valve in the open position, for any reason, will flood the refrigeration system with LN_2 and subcool the OF_2; a safe condition. Failure of the vent valve in a closed position, for any reason, will force the LN_2 level down to a point where the liquid nitrogen head on the system exceeds 6 psig. At this point, one of the relief valves will open, dropping the gas pressure on the vent side to 3 psig and allowing the LN_2 level to flood the heat exchanger coils. A slow, safe cycling operation will continue, maintaining OF_2 temperature somewhat above or below the set point, fluctuating slightly.

For any component failure short of rupture of the liquid nitrogen line, the system is fail-safe, and malfunctions can be taken care of without interruption of the basic system function. The common bulkhead tankage arrangement has been considered on FLOX/methane designs, where the details would be different, but the thermal control concept is feasible to achieve a common propellant temperature of 180°R. The type of LN_2 ground thermal control system illustrated here shows how simple the system might be. It is discussed further in Section 8.

4.3 PROPULSION MODULE THERMAL CONTROL - MULTIPLE TANK CONFIGURATION

There are many refrigeration system concepts which can be applied to a ground hold system for an OF_2/B_2H_6 propulsion module. Direct LN_2 or cold GN_2 injection into an insulation envelope surrounding the propellant tanks is one method. Closed loop systems, electromechanical refrigeration, and ground condensation and return of propellant boiloff, are others. If design requirements and objectives are adhered to, however, electromechanical refrigeration and propellant boiloff return systems are eliminated on the basis of dependence on power sources and safety considerations, respectively. The simplest, safest, most economical and reliable systems are the single pass and closed loop concepts.

The single pass LN_2 refrigerant system has already been discussed, as applied to a common bulkhead tank configuration. An objection to this system for a multiple tank configuration is the difficulty in mechanical and thermal design to properly distribute heat input to the LN_2. It is difficult to assure uniform mass temperature of the propellants, and localized subcooling and freezing of B_2H_6 at LN_2 temperatures with attendant inhibition of heat transfer may result.

Use of single-pass refrigerants other than LN_2, with vapor pressure curves more compatible with the freezing point of B_2H_6, have been investigated and found unsuitable because of cost, toxicity, or reactivity.

Closed loop systems permit use of refrigerants in the liquid range of B_2H_6, but the usual systems have disadvantages of reliance on a power source to drive the closed loop, installation expense, control complexity and operating cost.

Objections to both single-pass and closed loop systems disappear and advantages of both can be realized if single-pass LN_2 refrigeration is used to cool a gravity-fed closed loop system, as shown in Figure 4-4, with Freon 14 used as the secondary refrigerant. The basic principle is that used for design of the B_2H_6 transport dewar, except that the tetrafluoromethane tank is used as a source of refrigerant for the airborne heat exchanger coils on the propulsion module tanks, rather than as a thermal shield around a diborane storage tank. Thermal control of the Freon 14 refrigerant is the same as on the transport dewar, by ullage pressure comparison with a pressure controller setpoint. CF_4, maintained at constant ullage pressure and liquid temperature by the LN_2, is allowed to free-flood the airborne refrigeration system, maintaining both airborne propellants at the desired setpoint temperature. Prior to liftoff, the liquid supply valve to the airborne system is closed, allowing remaining liquid in the airborne system to boiloff and vent back to the refrigerant storage tank. At liftoff, the refrigerant system vent valve is closed, isolating the Freon 14 storage tank, and both airborne and ground lines are free to vent to atmosphere through the liftoff disconnects. Freon 14 is in the same hazard classification as nitrogen - inert and non-toxic.

Figure 4-4 is a simplified schematic of the entire thermal control system. In actual hardware design the single LN_2 supply valve to the Freon tank would be replaced by redundant valving and emergency manual by-pass, and redundant burst discs would be installed in parallel with both the Freon safety valves and LN_2 relief valves, as was done on the B_2H_6 transport dewar design. Failure analysis of the thermal control unit (TCU) is identical to that for the diborane transport dewar.

Thermal control with the TCU is by pressure controller setpoint, either manual or from an ullage pressure transducer in the airborne OF_2 tank. The range could go down to 195°R, if it were desired to freeze the B_2H_6. Alternate methods can be by direct temperature sensing in the Freon 14 tank, or by ullage pressure sensing in the Freon tank. Each method has its advantages, and ultimate selection would depend on sensitivity requirements, component reliability, temperature range requirements, and desirability of airborne versus ground sensing units. In any case, the systems are low pressure: less than 15 psig in the Freon system, and less than 45 psig in the LN_2 system. If the line sizes become too large or the response too slow, a small pump could be utilized to circulate freon.

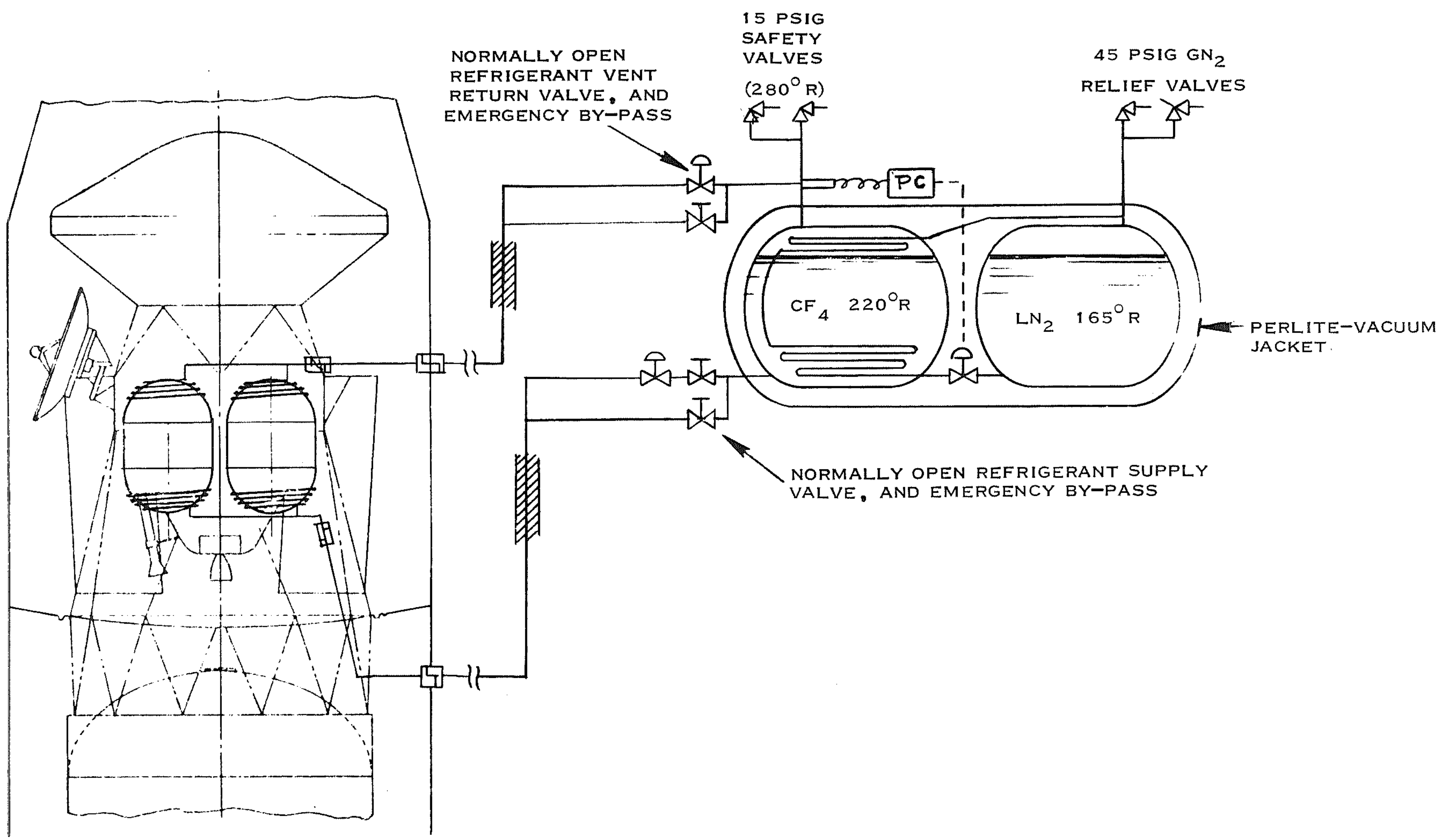


Figure 4-4. Propulsion Module Thermal Control, Two Tank Configuration

Propellant thermal control system advantages include:

- No propellant vent loss.
- Small, low pressure lines with non-toxic, inert fluids and simple disconnects.
- Independence from power requirements.
- Control range from 220°R to 280°R, adjustable to freeze diborane if desired.
- Fail-safe operation.
- Low operating costs - LH_2 boiloff only - @ < $25/day.
- Control by airborne or ground sensing.
- Seven-day thermal control capability without LN_2 resupply.

Overall operating cost for the system is estimated at less than $25/day for liquid nitrogen consumption, for both airborne and ground heat load. The airborne heat load will, of course, be dependent on final tank configuration, type of insulation, and insulation thickness. An estimate of the heat load (Appendixes A.1 and A.2) has been made, however, assuming two inches of foam insulation on each of three different tank configurations. Liquid nitrogen consumption for the worst case, four spheres, was $19.83/day. For two cylinders with spherical bulkheads, the cost was $15.92/day. For a common bulkhead tank, $12.70/day. The variation is in direct relation to the tank and insulation surface areas, with the insulation blanketing each tank separately; no attempt was made to optimize "cocooning" of the tanks.

Loss of refrigerant from any cause (line rupture, etc.) would result in a slow rise in propellant temperature and pressure. Assuming two inches of foam insulation on the tank, it will require at least 24 hours (Appendix A.3) for the OF_2 tank pressure to rise to 150 psig, providing a tank pressurization safety factor of more than two for personnel working in the area, based on an assumed tank working pressure of 400 psig. The diborane tank will require at least 48 hours to rise to the same value. In less than one day, the refrigerant lines can be replaced, or a spare TCU installed.

The thermal control unit can be built as a fixed unit or mobile. An 1,100 gallon dewar of LN_2 will permit a seven day resupply cycle. This together with the small Freon supply means the TCU trailer need be no more than 10 feet long. Refrigerant lines to the propulsion module would be armored flex lines, in both cases. Fixed units would probably be desirable for installation in the propellant lab and assembly buildings at the ESF, and in the fixed umbilical tower at the launch complex. A mobile unit could be used as a spare for any of the fixed units or to accompany the Propulsion Module from ESF to Complex 41. If the propulsion module is to be moved to the launch complex with propellants aboard, a TCU on the transporter would permit holding of the loaded module on the transporter indefinitely. In view of the 24-hour hold capability of the module without the TCU, and the availability of a mobile unit, it may not be necessary to build in a TCU on the transporter.

5

PROPULSION MODULE LOADING AND TRANSPORT

5.1 DESIGN REQUIREMENTS

Two ground rules have been adhered to in the study of diborane and oxygen difloride loading of a propulsion module:

1. Thermal control of the airborne tank propellants will be maintained between 210°R and 280°R, with a targeted prelaunch temperature of 220°R.
2. Two loading situations are to be considered; loading before encapsulation, followed by transport of the loaded spacecraft to the launch complex; and after encapsulation, with the spacecraft already mated to the launch vehicle at the launch complex.

Liquid oxygen difluoride is one of the most powerful oxidizing agents known, and is extremely toxic. Diborane, also very toxic, is pyrophoric and highly reactive. The use of these two cryogens as rocket propellants therefore requires AGE systems designed to meet dual basic requirements: dependable function with maximum safety. The systems must incorporate the purging, evacuating, passivating, transfer and safety procedures developed by the producers and users of liquid fluorine over the past ten years. Further precautions must also be taken in the nature of preliminary loading and training procedures before final loading of the spacecraft with flight propellants is accomplished. To minimize the hazard risk to spacecraft, launch vehicle, and launch complex, the following design ground rules are therefore recommended:

1. A propulsion module test and training article will be used in conjunction with any loading system before a flight article is used.
2. The test article and loading system will be integrated and initially validated with LN_2, then with OF_2 and B_2H_6.
3. Flight articles will be passivated and loaded at least once, before mating to the spacecraft. This may be done at the propulsion module contractor's plant or at KSC.

It is expected that some subsystem testing of the propulsion module with OF_2 and B_2H_6 will be required at the contractor's plant. Regardless of such exposure to these propellants, it is considered advisable to transport the module to the Kennedy Space Center in a completely clean, purged condition, with helium blanket pressure in the propellant tanks, and repassivate before mating to the spacecraft.

Two basic locations for propellant loading at the Cape, Figure 3-2, have been considered in this study. One, somewhere away from the immediate launch complex area - probably the ESF - followed by transportation of the encapsulated loaded spacecraft to the pad for mating to the launch vehicle. The other, at the launch pad itself, after the spacecraft has been mated. Each location has several options for storage and transfer methods, and is considered with respect to technical feasibility, reliability, and safety in the following paragraphs.

5.2 PROPELLANT LOADING AT THE ESF

5.2.1 EQUIPMENT AND SUBSYSTEMS. Figure 5-1 shows the essentials of a facility for loading OF_2 and B_2H_6 aboard a test or flight article propulsion module, away from the launch complex. Outside the building (e.g., Propellant Laboratory at the Explosive Safe Facility) are liquid and vent connections for the two propellant transports. Only one of the propellant systems will be active at any one time, although after loading the propellant transport may be left connected for emergency drain. Separation of the two parking spaces is therefore not critical, but they can be separated with no problem. Liquid nitrogen connections are provided for cold flow and pressure testing of the airborne and ground systems before propellants are introduced. To completely dry and inert the systems, separate vacuum pumps are connected to each propellant system to evacuate transfer system lines and the airborne tanks, prior to loading. A transfer system and airborne tank is first purged clean while connected to the disposal unit; the vacuum pump is then started and the system pumped down through a charcoal (or soda lime) tower to remove any residual B_2H_6 (or OF_2) molecules. After pumpdown, the absorbent tower is by-passed to attain a higher vacuum. The absorbent canisters are designed for easy removal, for disposal if contamination should occur. Note: for light weight propulsion module tanks incapable of withstanding a vacuum, a different purge blowdown procedure would be required to dry the system.

Inside the facility, each propellant system has a common-point manifold, with a transfer line and flex connection to the airborne propellant disconnect. Liquid propellant or LN_2 can be fed to this line, or the line can be vented or evacuated.

Vent connections for each transfer line are run separately to the disposal unit (see Section 6.1), atmosphere, or sampling valves.

Transfer lines can be helium purged from either the airborne disconnect end, or the transport end, to the vent and disposal line.

The two propellant systems are completely separated. There are no common lines or cross-connect possibilities other than those in the airborne engine propellant feed system itself.

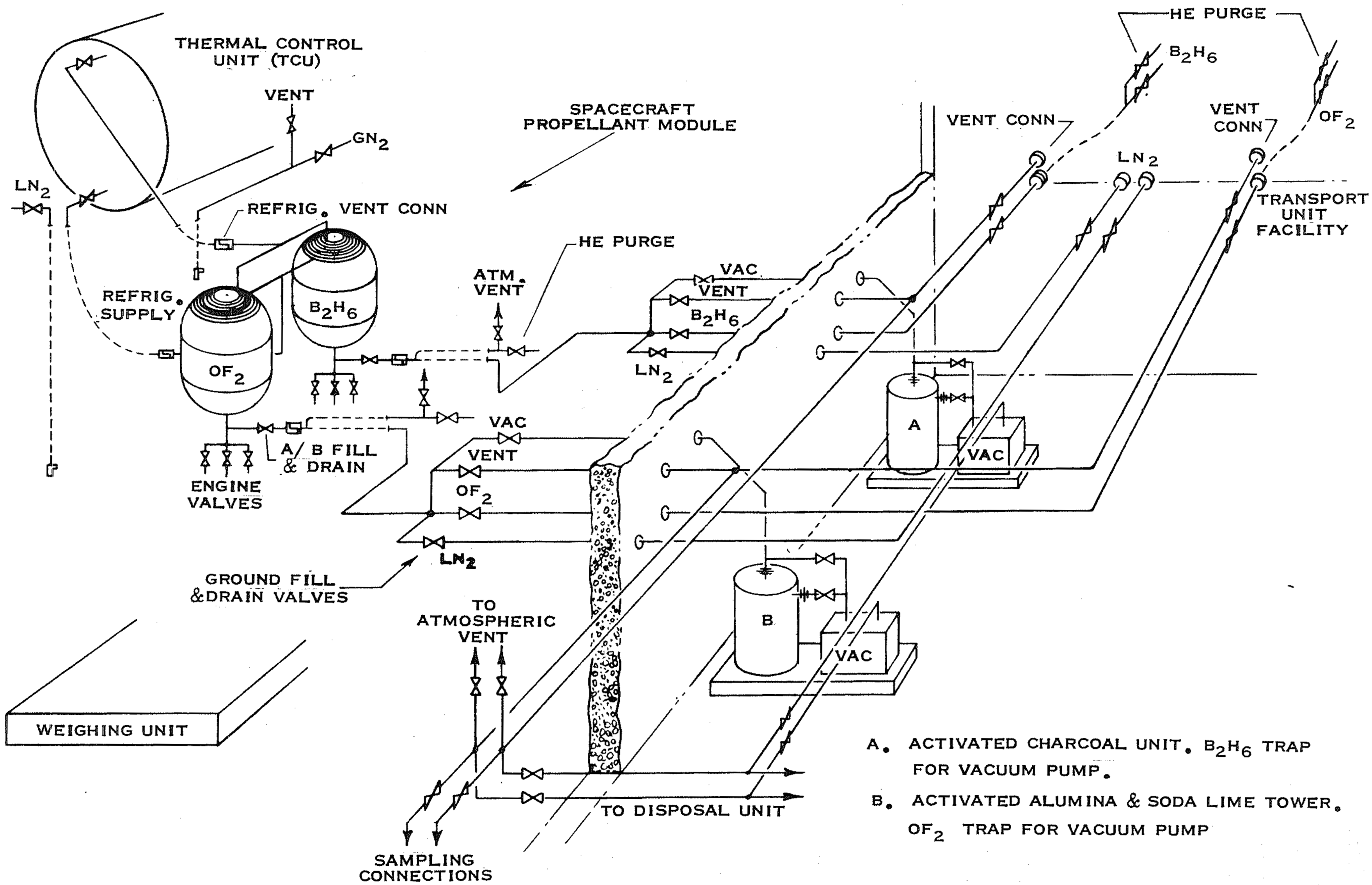


Figure 5-1. OF_2/B_2H_6 Propellant Module Loading Facility

The thermal control unit (TCU) is shown with flex hose connections for refrigerating the airborne propellant tanks with either 140°R LN_2, or 210° to 280°R refrigerant (CF_4). Propellant lines can be inexpensively foam insulated; vacuum or LN_2 jacketed lines are unnecessary. This facility can be new construction, or the Propellant Laboratory at the ESF can be readily adapted for use. The Laboratory has more than adequate conduits available for remote sensing and control, and the berm on the south wall has multiple four inch conduits running through to the outside, ideal for propellant, vent and vacuum lines. There is existing helium purge capability in the building.

5.2.2 LOADING PROCEDURE. It is assumed that the test or flight article propulsion module is received in a certified propellant clean condition with 20 psig helium blanket pressure in both tanks. After the ground system has been completely cleaned and functionally validated (initially using a test article), the propulsion module is installed and the refrigeration and propellant lines connected. Lines are not connected or disconnected until purge and sampling procedures have been performed. Remote control is provided from the Instrumentation Lab, together with TV Monitoring. Each of the integrated airborne ground propellant systems is then separately ambient and cold pressure checked, purged, evacuated, and passivated for 24 hours (OF_2 only) before loading.

Basically, remote liquid loading is accomplished by pressurized transfer at a low rate into an evaluated transfer line and airborne propellant tank. The airborne propellant tank is refrigerated, condensing chilldown gas until subcooled liquid flows. With 1/2 inch insulated lines, an airborne propellant tank will load in less than an hour.

Propellant drain when only one propellant is aboard is accomplished by inactivating the TCU and flowing ambient GN_2 through the refrigerating coil. Vapor pressure will empty the tank, and residuals are removed by repeated helium pressurization and blowdown, followed by evacuation and introduction of helium blanket pressure.

If both propellants are aboard, the oxidizer is drained first by setting the TCU to 250°R and expelling the OF_2 under 17 psig OF_2 vapor pressure. The TCU is then inactivated and ambient GN_2 flowed through the refrigerating coil, diborane discharging under its own vapor pressure. Residuals are removed as before, by helium pressurization and blowdown, followed by evacuation and repressurization with helium.

While detailed loading procedures will depend on final design, functional procedures can be outlined as follows:

1. Ambient and Cold Pressure Tests, Airborne and Ground Systems.

   a. Airborne Refrigerant lines.

      (1) Pressurize with GN_2 to proof pressure (50 psig), and leakcheck.
      (2) Blowdown to ambient.

(3) Fill with LN_2.
(4) Pressurize to proof pressure and leakcheck.
(5) Vent and return to ambient temperature and pressure (GN_2).

b. Airborne Oxidizer System, to Ground Fill and Drain Valve.

(1) Pressurize with He to 240 psig and leakcheck.
(2) Blowdown to ambient.
(3) Evacuate.
(4) Chilldown with refrigerant system to -320°F.
(5) Chilldown LN_2 line and ground oxidizer system through purge line vent.
(6) Fill spacecraft OF_2 system with LN_2 (50 psig).
(7) Isolate airborne and ground oxidizer system to ground fill and drain valve.
(8) Pressurize to 240 psig and leakcheck.
(9) Vent and drain (GN_2 in refrigeration coil, for ullage pressure). Leave under GN_2 blanket pressure.

c. Fuel System: same as Oxidizer System.

d. All systems, final condition: residual GN_2 blanket pressure at ambient temperature.

2. Purge and Contamination Tests (Starting with ambient temperature GN_2 blanket pressure).

a. Oxidizer System.

(1) Evacuate airborne system and ground system to OF_2 loading station fill and drain valve, or to transport fill and drain valve if transport is connected.
(2) Pressurize with He (100 psig).
(3) Blowdown and sample.
(4) Repeat purge sequence (1, 2, 3) until particulate contamination, moisture content and gas purity are within limits.
(5) Leave system under helium blanket pressure.

b. Fuel System: same as Oxidizer System.

c. All systems final condition: residual He blanket pressure at ambient temperature.

3. Passivation, Oxidizer System Only (starting with ambient temperature He blanket pressure).

a. Evacuate airborne system and ground system to OF_2 transport fill and drain valve.

b. Pressurize with helium.

c. Evacuate.

d. Passivate with GOF_2 at ambient temperature, reaching 240 psig proof and passivation pressure in 12 hours. Maintain pressure 12 additional hours. Do not vent GOF_2.

4. Oxidizer Load (Only after completion of procedures 1, 2, and 3 - Oxidizer System. Starting condition: 240 psig OF_2 at ambient temperature.)

   a. Activate TCU and chilldown to 140°R, allowing OF_2 line vapor pressure to decrease.

   b. Load OF_2 (20 to 50 psig He transfer pressure until propellant load weight is reached). Close airborne fill and drain valve. Set TCU to 220°R.

   c. Vent OF_2 transport dewar to disposal unit.

   d. Drain transfer line to OF_2 transport dewar (He purge pressure).

   e. Close transport fill and drain valve.

   f. Vent transfer line to disposal unit.

   g. He purge OF_2 transfer line from airborne fill and drain and from transport fill and drain, to disposal unit.

   h. Purge until sample is within acceptable toxicity limits.

   i. Final airborne oxidizer tank condition: LOF_2 at 220°R, 8.5 psia vapor pressure.

5. Oxidizer Drain (airborne oxidizer tank at 8.5 psia, 220°R. Helium blanket pressure only, in airborne fuel tank).

   a. Set TCU to 250°R and allow to stabilize.

   b. Vent OF_2 transport dewar to disposal unit.

   c. Open transport, ground, and airborne fill and drain valves.

   d. Inactivate TCU; flow GN_2 through refrigeration system to warm up tank.

   e. Close transport fill and drain valve when airborne tank is emptied.

   f. Pressurize airborne and ground oxidizer system to transport fill and drain valve, 100 psig He pressure.

   g. Vent transfer line to disposal unit.

   h. Repeat f and g three more times.

   i. Perform purge and contamination tests (Procedure 2).

j. Final airborne tank condition: residual He blanket pressure at ambient temperature.

6. Fuel Load (Only after completion of Procedures 1 and 2 - Fuel System. Starting condition: helium blanket pressure at ambient temperature).

   a. Evacuate helium blanket gas from airborne system and ground system to B_2H_6 transport fill and drain valve (5 torr minimum).

   b. Activate TCU and chill airborne fuel tank down to 220°R.

   c. Load B_2H_6 (20 to 50 psig He transfer pressure until propellant load weight is reached). Close airborne fill and drain valve.

   d. Vent B_2H_6 transport dewar to disposal unit.

   e. Drain transfer line to transport dewar (He purge pressure).

   f. Close transport fill and drain valve.

   g. Vent transfer line to disposal unit.

   h. He purge transfer line from airborne fill and drain and from transport fill and drain, to disposal unit.

   i. Purge until sample is within acceptable toxicity limits.

   j. Final airborne fuel tank condition: B_2H_6 at 220°R, less than 0.1 psia vapor pressure. Note: a helium blanket pressure to exceed one atmosphere in the tank is desirable if possible with the airborne system design.

7. Fuel Drain (airborne fuel tank at 220°R; oxidizer tank empty, 20 psig He blanket pressure).

   a. Vent transport dewar to disposal unit.

   b. Inactivate TCU; flow GN_2 through refrigeration system to warm up tank.

   c. Open transport, ground and airborne fuel fill and drain valves when airborne tank pressure rises above atmospheric.

   d. Transfer fuel to transport unit using airborne vapor pressure.

   e. Close transport fill and drain valve when tank is emptied.

   f. Pressurize airborne and ground fuel system to transport fill and drain valve, 100 psig He.

   g. Vent transfer line to disposal unit.

   h. Repeat f and g three more times.

   i. Perform purge and contamination tests (Procedure 2).

j. Final airborne tank condition: residual helium blanket pressure at ambient temperature.

The procedures as outlined leave the propulsion module tanks purged of propellants under positive helium blanket pressure, ready for mating to the bus and spacecraft, and for transport to the launch complex for final loading. If the propellants are left tanked and no leakage is detected within a day or two, Pad Safety will allow resumption of limited access to handle the wet spacecraft.

5.3 PROPULSION MODULE HANDLING

If the propulsion module is to be loaded only at the loading facility, never at the launch pad, then the drain sequences are omitted in the procedures outlined in Subsection 5.2.2, and final condition of the module will be fully loaded with propellants, maintained at 220°R by the loading facility TCU, with a positive helium blanket pressure.

After loading, the propulsion module will be mated to the bus, either in the assembly building or in the new S and A building at the Explosive Safe Facility. In the S and A building, the bus and module will be mated with the payload, and the complete spacecraft encapsulated in the shroud.

In these operations, the loaded module presents handling options with respect to GSE: should temperature control and drain capability be maintained while shifting the module from building to building, from one work dolly or ground transport vehicle to another, and during actual mating operations?

The insulated module has a capability of remaining without refrigeration for at least 24 hours without propellant tank pressures going over the safety limit for personnel in the area, "Safety limit" being one-half of design working pressure.

Since transfer operations between buildings are in the nature of only one hour, it would appear that such operations could best be made by disconnecting the module from the fixed TCU in one building, moving the module to a new dolly and building, and reconnecting to the fixed TCU in the new location. Drain capability is always available in the form of the transport dewars, held in readiness in the area whenever a loaded module is being handled.

Hoisting, transferring and moving the module with refrigerant lines and drain lines connecting it to GSE is at best awkward, complicated with other lines and umbilicals connected, and adds the risk of fouled or broken fluid lines endangering handling personnel. It is recommended that loaded propulsion modules be handled without thermal control and propellant drain lines attached, during transfer in and around the spacecraft assembly areas, just as Mariners and Surveyors have been handled in the past.

5.3.1 ENCAPSULATED SPACECRAFT WITH EMPTY PROPELLANT TANKS. Transport of the encapsulated spacecraft from the final assembly area to the launch complex is relatively simple when there are no propellants aboard. No provision is required for propellant thermal conditioning, vapor disposal, or drain capability enroute. The caravan, Figure 5-2, consists of the tow vehicle, spacecraft ground transport vehicle (GTV), environmental control unit (ECU), and the power supply trailer. This is the same arrangement that has been used for other unmanned spacecraft operations such as Surveyor, OAO, Mariner and ATS, and with the exception of the tow vehicle and GTV, the equipment is in existence and applicable to the Space Storables program. The tow vehicle required is a standard commercial tractor. The GTV is new GSE, and must be designed to accommodate both the spacecraft/shroud configuration and the particular requirements of the loading concept chosen. Without propellants aboard the spacecraft, only the monitor and control console is required as support equipment on the transport vehicle. It is probable that the console will be skid mounted and remain cable-connected to the encapsulated spacecraft, on or off the transport.

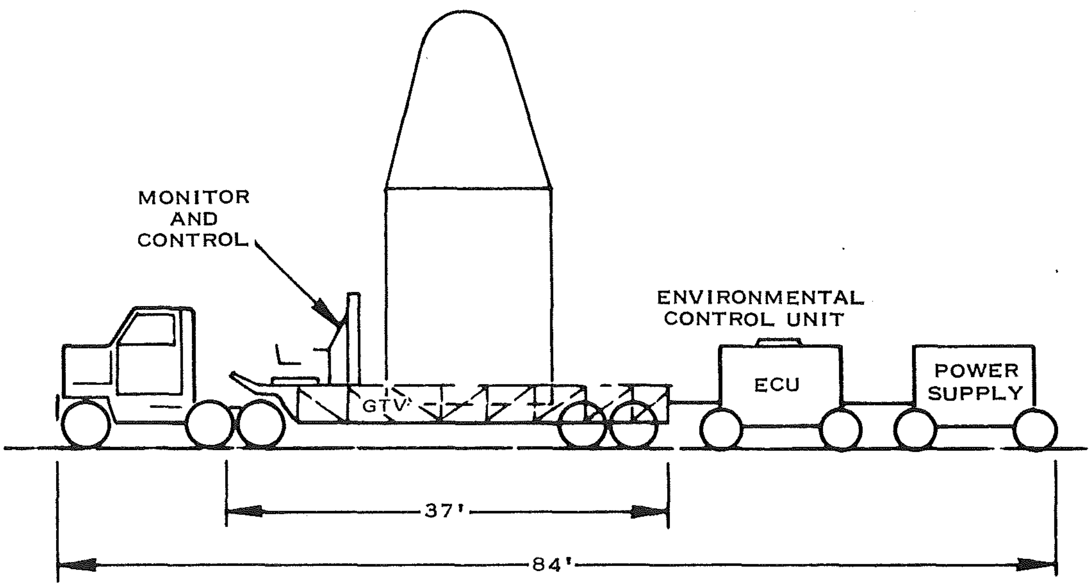


Figure 5-2. Encapsulated Spacecraft Caravan, Without Propellants

5.3.2 ENCAPSULATED SPACECRAFT WITH PROPELLANT TANKS LOADED. With propellants aboard the spacecraft, consideration must be given to shroud environmental control exhaust disposal, in-transit thermal control of propellants, and emergency propellant drain capability. The same basic GTV required for untanked spacecraft transport would be used for tanked transport, but could include space for a skid-mounted thermal control unit and a power supply unit as well. Transport length would be increased approximately seven feet, but would eliminate one trailer, for the power supply. Overall length of the GTV would be approximately 44 feet, allowing parking in the 50 × 50 foot spacecraft assembly room at the Explosive Safe Facility.

The environmental control unit trailer, the same unit as used in the untanked spacecraft caravan, would trail the GTV, and could be followed by a vapor disposal unit as shown in Figure 5-3.

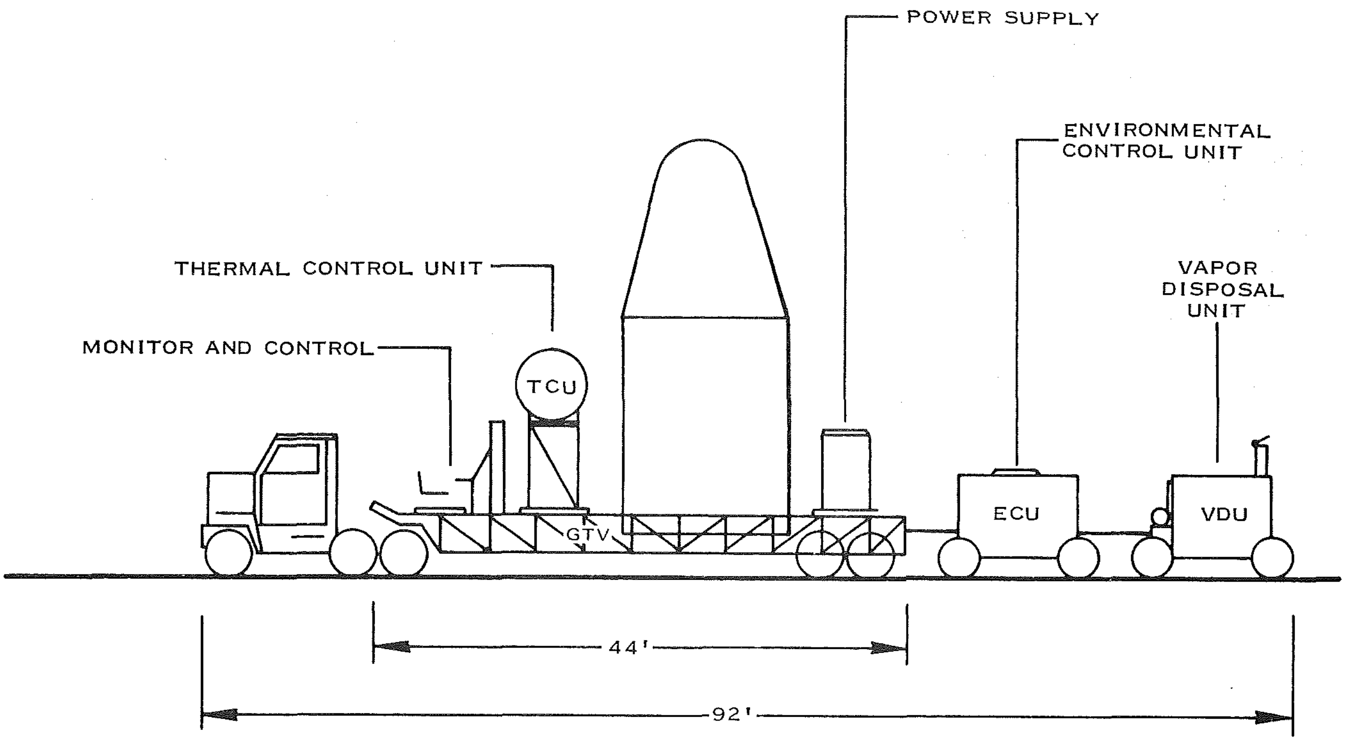


Figure 5-3. Tanked, Encapsulated Spacecraft Caravan

Environmental control exhaust, approximately 1000 cfm, would normally by-pass the VDU and vent to atmosphere. If the propellant vapor sensors located in the exhaust duct indicated leakage, however, the transport monitor would switch the conditioned gas exhaust over to vapor disposal mode.

Propellant drain capability, if the decision were made to require it during transport, would be provided by the mobile propellant fill and drain dewars. The need for such a capability is doubtful, but if propellant drain were required enroute, the dewar could be brought alongside the GTV, connected to the propellant module fill and drain disconnect, the propellant unloaded, and the dewar removed to a safe area.

Thermal control of the propellants while in transport, at any desired temperature from 210° to 280°R, can be accomplished with the same basic unit as used in the loading facility and at the launch pad, fail-safe with loss of all power and pneumatics, capable of maintaining the set tank temperature for six or seven days, unattended. In the event of unforeseen accident destroying the TCU or rupturing the refrigerant lines, the OF_2 temperature and pressure would rise very slowly, allowing up to 24 hours to replace the refrigerant lines, to replace the skid-mounted TCU with the mobile unit, to drain the propellants, or to return the caravan to the Explosive Safe Area.

Transport of the loaded propulsion module without thermal control during transit is also possible, because of the slow temperature and pressure rise characteristics of the insulated module. In this case, the transport vehicle design would not include a TCU, and handling would be simplified. The loaded spacecraft would be disconnected from the fixed TCU at the Final Assembly Building, transported to the launch complex, mated to the launch vehicle, and connected to the fixed umbilical tower TCU. If delays were to occur enroute, or at the launch pad, the mobile TCU would always be available for connection to the spacecraft for thermal control, if required.

Heat flux estimates of a two inch foam insulated propulsion module (Appendix, A-3) indicates a minimum time of 24 hours without refrigeration, before the OF_2 tank would rise from 220°R to 305°R and 150 psig. Assuming 400 psig tank working pressure, a safety factor of more than two would exist for personnel working in the area, for at least 24 hours. The oxygen difluoride tank is limiting, since the diborane tank would require more than twice the time to reach 150 psig.

At three to five miles per hour, caravan in-transit time from the loading facility to Complex 41 would be one to two hours.

5.3.3 COMPARISON OF EMPTY VERSUS PROPELLANT LOADED SPACECRAFT TRANSPORT. A comparison of relative advantages and disadvantages of empty versus loaded spacecraft transport is summarized in Table 5-1. The summary relates only to the transportation procedure itself and not to its impact on major issues such as choice of loading location, overall time schedule, etc. The latter will be discussed in detail in the conclusions and recommendations section of this report.

Table 5-1. Comparison of Empty versus Loaded Spacecraft

Factor	Spacecraft	
	Empty	Loaded
Toxicity Hazard	No	Yes
Vapor Disposal Unit Required	No	Yes
Propellant TCU Required	No	Optional
Drain Capability Required	No	Optional
Transport Time Criticality	None	With TCU: None Without TCU: 24 hours
Overall Caravan Length	~ 84 ft	~ 84 to 92 ft
Degree of interference with Normal Traffic	-	Somewhat greater (Toxicity & Caravan length)
Confidence Level in Integrity of Spacecraft Propellant Systems	-	Greater. (Systems subject to Road Vibration and longer time loaded)

5.4 LAUNCH COMPLEX PROPELLANT LOADING SYSTEM

Propellant loading at the launch complex with the encapsulated spacecraft mated to the launch vehicle can be accomplished in several ways. Selection of the best system will depend on technical feasibility of the system, personnel safety, overall risk to the mission, and cost. The number and frequency of missions requiring these Space Storable propellants would also influence the choice of permanent or mobile installations. Three methods of loading are considered:

1. Transfer from dewars at the 12th level of the umbilical tower or missile service tower.
2. Liquid transfer from ground level, mobile or permanent dewars.
3. Vapor transfer from ground level from mobile dewars.

5.4.1 TRANSFER FROM DEWARS AT THE 12TH LEVEL. This method of loading the propulsion module has an apparent advantage of short transfer lines and low transfer pressure in the dewar. Both factors are overshadowed by attendant disadvantages, however:

The transfer dewars must either be permanently installed on the fixed umbilical tower (the umbilical tower personnel elevator is inadequate for lifting) or mobile and lifted to the upper MST levels by the freight elevator or hoist. Whether permanent or mobile, the dewars will be new design, regardless of transfer pressure requirements. There are no B_2H_6 or OF_2 dewars in existence that meet these requirements.

If permanently installed, the dewars become a permanent hazard in the umbilical tower, and in addition, require a propellant transfer system from ground level for filling. If mobile, the dewars can be designed to be lifted in the mobile service tower elevator for loading the propulsion module, but when the service tower is retracted, no drain capability would exist. The many connections between ground MST and spacecraft for propellant, LN_2, purge and evacuation are vulnerable to contamination.

If drain capability is desired, then drain should be through tower lines to ground level to remove the propellants from the spacecraft area as rapidly as possible. Further, drain should be into mobile ground level dewars to facilitate rapid removal of bulk propellants from the entire launch complex area.

The "short transfer line" advantage then, is actually a disadvantage, an extra system in addition to tower lines which are required for drain but which are also capable of loading the spacecraft.

If loading is done from the twelfth level, propellant measurement is almost certainly restricted to on-board sensors. Weight measuring devices in the upper structural levels of the tower would be cumbersome, inaccurate, expensive, and too demanding of available space.

This method of loading is the least attractive when compared to ground level loading.

5.4.2 LIQUID LOADING FROM GROUND LEVEL. Loading from ground level with liquid or vapor has inherent advantages over high level loading:

There is no storage at upper levels where emergency egress is difficult. Effect on service tower and umbilical tower space availability is almost negligible. Using mobile dewars, propellants need only be at the complex when the spacecraft is loaded, and can be rapidly removed from the launch complex area in an emergency.

A single system can be used for fill and drain, minimizing installation cost and wetted system hazard, and assuring intact, passivated, tested drain lines after the module is loaded.

Loading system auxiliary equipment and access is more adaptable to ground level location (LN_2 connections, sampling, vapor disposal, vacuum units).

Propellant weighing systems are more adaptable to ground level environment.

Dewars, if new design is required, are not restricted in physical dimension.

Tower modifications (structural, hoist, access ways) are not required.

Loading from ground level rather than an upper level obviously has many advantages. Loading of liquid cryogenic propellants from ground level, however, presents serious technical difficulties. The quantities involved are small, approximately 20 cubic feet, and the transfer lines are small in diameter and long in overall length ($\sim$ 1/2 inch diameter, 200 feet long). To transfer liquid and avoid boiloff, the line must be pre-chilled to temperatures below the transfer pressure saturation temperature. The line must also be well-insulated to maintain liquid phase, and must be evacuated to assure removal of all contaminating (N_2) and noncondensable gases (helium) which would otherwise be trapped in the spacecraft propellant tanks.

These requirements indicate a refrigerant jacketed co-axial transfer line with external insulation and a liquid refrigerant system (supply tank, condenser, expansion tank, etc.). LN_2 can be used for the OF_2 refrigerant, but not for the B_2H_6 line since it would freeze the B_2H_6 unless held above 165 psig. Refrigerant jacketed co-axial lines with external insulation are also difficult to leak-check.

From a cost standpoint, a further objection to liquid loading from ground level is the requirement for a new OF_2 transfer dewar. The Allied trailer is limited to a 70 psi transfer pressure, insufficient to elevate -320°F OF_2 to 135 feet. (105 psi minimum, required.)

5.4.3 VAPOR LOADING SYSTEM. The advantages of loading from ground level can be realized and the objections to liquid loading eliminated if a vapor phase loading system is used. The vapor system has an added advantage of low-pressure operation as compared to liquid loading, but is slower. Figure 5-4 is a schematic of the propellant loading system suggested for ITL Complex 41.

5.4.3.1 Equipment and Subsystems. Schematically, the system is identical to that used at the ESF propellant module loading facility, with two additions. Small vaporizing coils have been added to the transport dewars, and condensers added (possibly) to the fill lines at the upper level, just before the airborne disconnects. All service connections and GSE are identical to those used at the ESF facility, including the 800 pound B_2H_6 dewar and the 5,000 pound Allied OF_2 transport. As before, the two propellant systems are completely separated, with no common lines or cross-connect possibilities. The thermal control unit and airborne refrigerating systems have been omitted from the schematic, for clarity.

5.4.3.2 Loading Procedure. It is assumed that the flight article propulsion module (or test article for initial system validation) is received in a certified propellant clean condition with 20 psig helium blanket pressure in both tanks, and has been loaded with flight propellants at least once, elsewhere.

After the ground propellant loading system has been completely cleaned and validated, the propulsion module is installed and the refrigeration and propellant lines connected. Each of the integrated propellant systems is then hot and cold pressure checked, purged, evacuated, and passivated (OF_2 only) before loading. During passivation, the OF_2 airborne and ground propellant systems are under 240 psig ambient OF_2 pressure, and the launch site must be considered in a "loading" condition with respect to safety procedures.

Loading of OF_2 begins after the 24 hour passivation procedure is complete. To load, the airborne refrigeration system is activated and set at 140°R, condensing vapor at 271°R (50 psig saturation temperature) into liquid OF_2 in the airborne tank. As condensation occurs and system pressure tends to decrease, liquid OF_2 flows into the vaporizer from the transport trailer, vaporizing and maintaining system pressure. The process continues until airborne sensors or ground vehicle weight indicates that the propellant tank loading is complete.

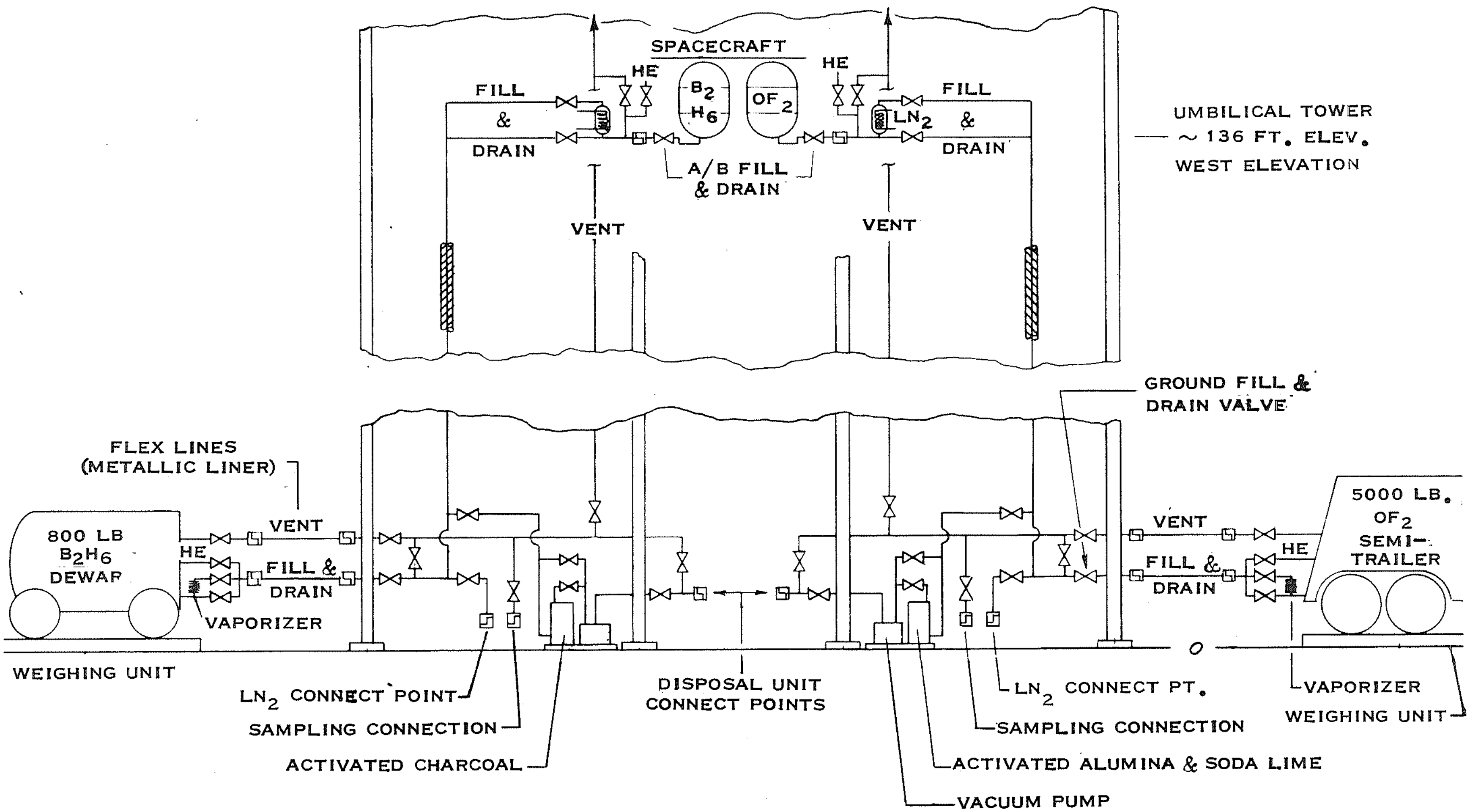


Figure 5-4. Complex 41 Propellant Loading System

Loading time is dependent on the condensation capability of the airborne refrigeration systems. A detailed thermal analysis of propellant vapor condensation rate and load time can only be done if airborne design details are available. A reasonable approximation can be made, however, based on the following assumptions:

1. Film condensation, (conservative) rather than dropwise condensation.
2. No noncondensable gases present (ideal).
3. Vapor at saturation temperature (line precooler prior to entering airborne tank, if required).
4. Thirty-six inch diameter cylindrical airborne tanks, spherical ends, 54 inch overall length.
5. Half of upper spherical end-cap area at refrigerant temperature (140°R LN_2 temperature, for OF_2 tank).
6. Fifty psig vapor transfer pressure.
7. No increase in condensation rate from vapor bubbling up through subcooled condensate, after loading starts (conservative).
8. Nominal values of propellant liquid viscosity, density and thermal conductivity near condensation temperature, rather than variable values over the ΔT involved.

With the above assumptions, loading time of the OF_2 vapor transfer system is 42 minutes (Appendix A.4).

If final design were to invalidate some of the assumptions, or if a more rapid loading system were desired, then the high level condenser shown in the schematic, Figure 5-4, would be included in the design. With the high level condenser in operation, both liquid and vapor will flow into the airborne tank under system pressure. One hundred percent liquid would flow only if the condenser were designed with at least 65 times the condensing capability of the airborne system. (Saturated vapor/liquid OF_2 density ratio is $\sim$ 65:1 at 50 psig.) This would be undesirable, since the condenser should be maintained free of condensate to facilitate ground weighing.

Backflow of liquid from the airborne tank is prevented by an airborne liquid (manometric) trap, shown as a dog-leg in the line at the airborne tank, in the schematic.

Airborne propellant drain is accomplished by setting the TCU to 250°R (17 psig OF_2 vapor pressure) and venting the transport trailer to the disposal unit with airborne and ground fill and drain valves open.

Loading of B_2H_6 is similar to that for OF_2, except that no passivation is necessary, and the airborne refrigeration system is set at 220°R, condensing B_2H_6 vapor at a 15 psig saturation temperature of 351°R. Loading starts with the airborne tank chilled down (TCU in operation with OF_2 already loaded) and the diborane transfer line evacuated. In-transit time of the first diborane to be vaporized (from 250°R transport temperature, chilling on expansion, then warming from line temperature) would be extremely short. As more propellant transfers the pressure can be increased, and the line will chill down. The first diborane to vaporize might conceivably reach 100°F, but in-transit time would be less than one minute and decomposition in the order of 0.005 percent, (see Figure B-7). Thereafter, as line temperatures dropped below 0°F, decomposition would be non-existent.

Transfer time for B_2H_6 will be approximately 96 minutes (Appendix A.4) and use of a high level condenser in the system is optional, dependent on final airborne design and desired loading time, as with the OF_2 loading.

B_2H_6 drain would normally be accomplished after OF_2 drain, inactivating the TCU and allowing rising vapor pressure to transfer the fuel to the ground transport. If OF_2 is to remain aboard, the airborne pressurization system would have to be used to drain the diborane.

Detailed loading procedures will depend on final design of components and installation. Functionally, the loading procedures are as follows:

1. Ambient and Cold Pressure Tests, Airborne and Ground Systems.

   a. Airborne Refrigerant Lines.

      (1) Pressurize with GN_2 to proof pressure (50 psig) and leakcheck.
      (2) Blowdown to ambient.
      (3) Fill with LN_2.
      (4) Pressurize to proof pressure and leakcheck.
      (5) Vent and return to ambient temperature and pressure (GN_2).

   b. Airborne Oxidizer System, to Ground Fill and Drain Valve.

      (1) Pressurize with He to 240 psig and leakcheck.
      (2) Blowdown to atmospheric.
      (3) Evacuate.
      (4) Chilldown airborne tank with TCU to -320°F.
      (5) Chilldown LN_2 line and ground oxidizer system through fill and drain line.
      (6) Fill spacecraft OF_2 system with LN_2, 50 psig.
      (7) Isolate airborne and ground oxidizer system to ground fill and drain valve.
      (8) Pressurize to 240 psig and leakcheck.
      (9) Vent and drain (GN_2 in refrigeration coil, for ullage pressure). Leave under GN_2 blanket pressure.

   c. Fuel System: Same as Oxidizer System.

d. All Systems, final condition: residual GN_2 blanket pressure at ambient temperature.

2. Purge and Contamination Tests (Starting with ambient temperature GN_2 blanket pressure.)

   a. Oxidizer System.

      (1) Evacuate airborne system and ground system to OF_2 ground fill and drain valve, or to transport fill and drain valve if transport is connected.
      (2) Pressurize with He (100 psig).
      (3) Blowdown and sample.
      (4) Repeat purge sequence ((1), (2), and (3)) until particulate contamination, moisture content and gas purity are within limits.
      (5) Leave system under helium blanket pressure.

   b. Fuel System: Same as Oxidizer System.

   c. All Systems final condition: residual helium blanket pressure at ambient temperature.

3. Passivation, Oxidizer System Only (Starting with ambient temperature He blanket pressure.)

   a. Evacuate airborne system and ground system to OF_2 transport fill and drain valves.

   b. Pressurize with helium.

   c. Blowdown and evacuate.

   d. Passivate with GOF_2 or GF_2 at ambient temperature, reaching 240 psig proof and passivation pressure in 12 hours. Maintain pressure 12 additional hours. Do not vent GOF_2.

4. Oxidizer Load (Only after complete of Procedures 1, 2, and 3 - Oxidizer System; Airborne and Ground Fill and Drain Valves still open, 240 psig OF_2 at ambient temperature.)

   a. Activate TCU and chill down to 140°R, condensing OF_2 vapor at 271°R.

   b. Continue loading OF_2 ($\sim$ 50 psig He transfer pressure until propellant load weight is reached).

   c. Close airborne fill and drain valve.

   d. Set TCU to desired propellant temperature (220°R).

   e. Vent OF_2 transport dewar to disposal unit.

f. Close transport fill and drain valve.

g. Vent transfer line to disposal unit.

h. He purge OF_2 transfer line from airborne fill and drain and from transport fill and drain, to disposal unit.

i. Purge until sample is within acceptable toxicity limits.

j. Final airborne oxidizer tank condition: LOF_2 at 220°R, 8.5 psia pressure.

5. Oxidizer Drain (Airborne oxidizer tank at 8.5 psia, 220°R. He blanket pressure only in airborne fuel tank).

   a. Set TCU to 250°R and allow to stabilize.

   b. Vent OF_2 transport dewar to disposal unit.

   c. Open transport, ground, and airborne fill and drain valves.

   d. Inactivate TCU; flow GN_2 through refrigeration system to warm up airborne tank.

   e. Close transport drain valve when airborne tank is emptied.

   f. Pressurize airborne and ground oxidizer system to transport fill and drain valve, 100 psig He.

   g. Vent transfer line to disposal unit.

   h. Repeat f and g three more times.

   i. Perform purge and contamination tests (Procedure 2).

   j. Final airborne tank condition: residual He blanket pressure at ambient temperature.

6. Fuel Load (Only after completion of Procedures 1, 2, 3, and 4. Starting condition: helium blanket pressure, airborne tank at 220°R.)

   a. Evacuate airborne system and ground system to B_2H_6 transport fill and drain valves (5 torr minimum).

   b. Open ground and airborne fill valves.

   c. Raise transfer pressure to 15 psig.

   d. Close airborne fill and drain valve when propellant load is reached.

   e. Vent B_2H_6 transport dewar to disposal unit.

   f. He purge transfer line to transport dewar.

   g. Close transport drain valve.

h. Vent transfer line to disposal unit.

i. He purge transfer line from airborne fill and drain and from transport fill and drain, to disposal unit.

j. Purge until sample is within acceptable toxicity limits.

k. Final airborne fuel tank condition: B_2H_6 at 220°R, less than 0.1 psia vapor pressure.

7. Fuel Drain (Airborne fuel tank at 220°R; oxidizer tank empty, 20 psig He blanket pressure.)

a. Vent transport dewar to disposal unit.

b. Inactivate TCU; flow GN_2 through refrigeration system to warm up tank.

c. Open transport, ground and airborne drain valves when airborne tank pressure rises above atmospheric.

d. Transfer fuel to transport unit using airborne vapor pressure.

e. Close transport drain valve when airborne tank is emptied.

f. Pressurize airborne and ground fuel system to transport fill and drain valves, 100 psig He.

g. Vent transfer line to disposal unit.

h. Repeat f and g three more times.

i. Perform purge and contamination tests (Procedure 2).

j. Final airborne tank condition: residual He blanket pressure at ambient temperature.

The procedures as outlined leave the propellant tanks purged and ready for demating of the spacecraft. In an emergency, both propellants can be unloaded at once by venting the dewars, inactivating the TCU, and warming up the refrigeration system, or using the airborne pressurization system for expulsion. Purge procedures can also be reduced in emergency, to line purge only prior to disconnect, purging the airborne tanks later at the ESF, when time permits.

If the Propulsion Module is tanked at the ESF, then the type of piping to mobile dewars at the base of the Umbilical Tower described above can serve as an Emergency Drain System.

6

RELATED EQUIPMENT

In addition to the propellant storage, loading, and temperature control equipment already discussed, the propulsion module will require much more Operational Support Equipment (OSE). [OSE is a JPL expression for all the electrical, mechanical, or electronic equipment required to assemble, handle, checkout, and launch a spacecraft. It is, then, essentially the same as Aerospace Ground Equipment (AGE) or Ground Support Equipment (GSE) which are USAF and NASA terms usually used for launch vehicles.] A group of ground handling fixtures, carts, and slings will be required to encapsulate and erect the spacecraft whether it is wet or dry. Special test and checkout consoles will be necessary whether the work is performed in the ESF or out at the launch complex. Most of this required equipment is not affected by whether the propulsion module uses a monopropellant, a solid motor, or space storable propellants. There are, however, three or four large items which should be briefly discussed because they are influenced by the cryogenic and toxic nature of space storable propellants.

6.1 PROPELLANT VAPOR DISPOSAL

Special safety precautions are necessary when venting propellant vapors which are highly flammable, corrosive, explosive, and/or toxic. At the Titan Launch Complex, the Aerozine 50 and N_2O_4 storage tanks are free vented through 200 foot high stacks. Burners are often used to dispose of highly flammable fuels. Fluorine sites have used several techniques to dispose of toxic vapor: charcoal beds to burn the vapor or water deluge and a trough to a drain basin to decrease the concentration and wash it away (and cool surrounding hardware). Rocket motor exhausts are "scrubbed" in a water spray tower. Test facilities for toxic propellants have often been located in such remote areas that controlled free vent is judged safe.

For handling a Space Storable Propulsion Module, it would obviously be extremely advantageous to be able to contain and neutralize any propellant vent, leak or spill with no toxic exhaust. It would also be ideal to have readily available drain receivers which could collect the entire propellant load in just a few minutes if an emergency arose. Several techniques including charcoal beds, water spray, and lime solution baths were reviewed for disposal units. Requirements vary from consuming about ten pounds of propellant vapor from a routine storage tank blowdown to handling an emergency dump of 2,000 pounds for a full load. It is recommended that a chemical vapor disposal unit (VDU) be used for routine vents or blowdowns of OF_2 systems and a burner for B_2H_6. LN_2 cooled dewars are recommended for emergency drain receivers.

6.1.1 DISPOSAL REQUIREMENTS. Routine propellant loading and draining operations necessitate venting propellant vapor from tank ullages (Figure 6-1). For filling the propulsion module, the storage tank will be pressurized with GN_2. When draining is required, or for standby, the storage tank must be vented. Depending on the temperature of the cryogen, it will have a partial pressure of saturated vapor in the ullage. For example, consider the Allied fluorine trailer with approximately 55 ft^3 capacity. If the OF_2 were at 140°R, with a vapor pressure of only 0.012 psia, then a trailer blowdown would involve only 0.03 pound of OF_2 vapor, which is insignificant. If the OF_2 were at 230°R, with one atmosphere vapor pressure, then a blowdown would involve 15 pounds of vapor, which is substantial. Blowdown of the diborane trailer of 32 ft^3 volume means almost two pounds B_2H_6 vapor at 280°R.

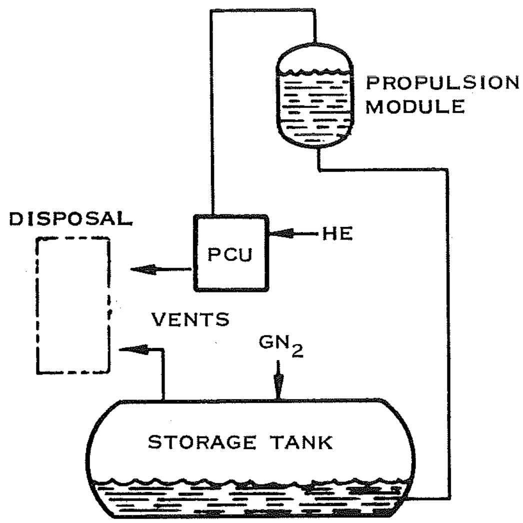


Figure 6-1. Tank Ullage Venting

The propulsion module can be drained back into the fill vessels or emergency drain receivers by warming the heat exchanger coils around the airborne tanks. The airborne tank and fill lines would end up at about 15 psi approaching ambient temperature. This vapor should be vented through the VDU by alternately pressurizing with very dry helium and blowing down. With a volume of about 30 ft^3 in the spacecraft tank and the fill lines, the total vapor vented will amount to about four pounds OF_2 and two pounds B_2H_6.

One possible requirement for safe vapor disposal arises in case of a leak in a tanked spacecraft. The leaking propulsion module is encapsulated in the nose fairing shroud except for the passivation tanking period in the ESF, if utilized. An Environmental Control Unit (ECU) will provide a flow of about 1000 cfm to "air condition" the shroud. A possible arrangement is to sense the exhaust for evidence of leakage (Figure 6-2).

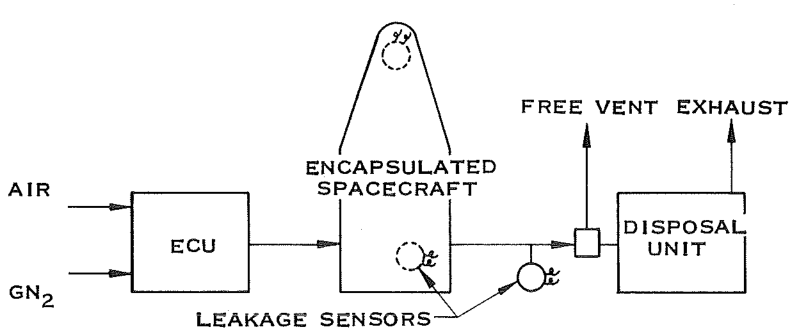


Figure 6-2. Conceptual Vapor Flow and Leakage Sensors

If any indication of propellant vapor were sensed — probably 0.01 ppm will be the sensitivity of the instrumentation — the ECU inlet would be switched from air to GN_2 and the exhaust from free vent to the disposal unit. Table 6-1 summarizes the several types and amounts of vapor flows which may occur. It indicates that leaks mixed in the shroud exhaust or Propellant Lab building air conditioning exhaust are very dilute: less than 0.01 ppm up to 20 ppm.

Table 6-1. Propellant Vapor Disposal Unit Requirements

	OF_2			B_2H_6		
	Rate	Concentration	Total	Rate	Concentration	Total
Vent storage tank and lines 55 ft^3 OF_2 Trailer: @ 140°R	10 cfm	200 ppm	0.03 lb			
@ 230°R	10 cfm	25%	15 lb			
32 ft^3 B_2H_6 Trailer @ 280°R				5 cfm	10%	2 lb
Vent S/C tank and lines 30 ft^3 × 15 psi @ 70°F	10 cfm	100%	4 lb	10 cfm	100%	2 lb
Leak in spacecraft propellant system mixed in shroud exhaust @ 1000 cfm GN_2	1 cc/s	2 ppm	0.23 lb in 8 hrs	1 cc/s	2 ppm	0.12 lb
Leak outside spacecraft shroud in GSE mixed in room A/C @ 1000 cfm air	10 cc/s	20 ppm	2.3 lb in 4 hrs	10 cc/s	20 ppm	1.2 lb
Spill outside spacecraft at disconnect 1000 cc mixed in A/C for P. L. or UES @ 1000 cfm air	instant	30%	3 lb	instant	10%	1 lb

NOTE: Emergency drain of complete propellant load not included.

The maximum amount of propellant which might ever need disposal is a full tank load: 1,900 pounds OF_2 and 650 pounds B_2H_6. To be helpful during an emergency, this dump should be completed very quickly - say, in less than 5 minutes. This would mean very high flows, like 1,600 cfm, of pure saturated OF_2 vapor.

Can a Propellant Vapor Disposal Unit concept be envisioned which can neutralize minute quantities (less than a pound) of very dilute (0.01 ppm) vapor as well as full load (2,000 pounds) pure vapor? Can a single such unit handle leaks and spills of either propellant and even an emergency drain of one and then the other propellant, in spite of their hypergolicity?

6.1.2 OF_2 DISPOSAL CONCEPTS. The classic fluorine disposal unit is a charcoal bed. For OF_2, the reaction is

$$2\ OF_2 + 2\ C \rightarrow CF_4 + CO_2 + \text{heat (ideally)}$$

The products, tetrafluoromethane and CO_2, are chemically inert and non toxic. Reference 25 states that amorphous carbon and charcoal are highly hypergolic with fluorine and react smoothly at all conditions, even at very low fluorine concentrations such as 0.3 percent. A typical proven fluorine/charcoal reactor design uses 3/8 inch charcoal bits.

For our maximum case of 1,900 pounds OF_2 in 5 minutes, about 500 pounds of charcoal would be required, and would generate extreme heat. The fact that OF_2 is not as active as F_2 suggests that the reaction with charcoal might be delayed or incomplete. Reference 26 recommends 100°C bed temperature to minimize unreacted OF_2. Another drawback is the very low concentrations of a leak, which conceivably might be absorbed and later let go violently. Convair tests reported in Reference 12 show that "spills of 30 percent FLOX onto charcoal spread over a flat confined surface..., resulted in a very smooth burning reaction, up to 40 percent efficient". But virtually perfect efficiency is required for a VDU. For all these reasons, charcoal does not seem to satisfy our vapor disposal needs.

A propane burner might be used to dispose of OF_2. Such a unit would consist of a burner stack, propane supply and control system, and an air blower. Such a system may be smaller and easier to build, supply, and control than a charcoal system. To maintain the flame at very low OF_2 concentrations the burner would run rich continuously. HF would be exhausted which is unacceptably toxic itself. Therefore a propane burner disposal, also requires an auxiliary scrubber for HF products.

A third approach to disposing of OF_2 vapor is to scrub with a basic water solution. The water-fluorine reaction can be explosive, but becomes combustive with fog spray. The water-fluorine product, HF, is toxic and requires secondary disposal.

$$1{,}850\ \text{lb}\ OF_2 + H_2O \rightarrow O_2 + 1{,}370\ \text{lb HF}$$

In Reference 27, Allied Chemical showed that dilute aqueous solutions of ammonia effectively decontaminated about 80 percent of the gaseous OF_2 test sample. But the product, ammonium fluoride, is soluble and very toxic. Therefore further or other neutralization is required. Lime is an effective neutralizer for the hydrofluoric acid formed from water reaction producing an insoluble non-toxic salt:

$$2\ HF + Ca\ (OH)_2 \rightarrow CaF_2 + 2H_2O$$

$$OF_2 + Ca\ (OH)_2 + H_2O \rightarrow CaF_2 + 2H_2O + O_2 + 123\ \text{Kcal/mole of}\ OF_2$$

When the lime solution has been reacted with OF_2, it can be drained out into a pit or holding pond without fear of ecological damage.

If the total load of 2,000 pounds OF_2 is reacted by dilute lime solution, the heat of reaction will be more than 8 million Btu:

$$\Delta H,\ 2{,}000\ \text{lb}\ OF_2 = 2{,}000 \times 453.6 \times 123 \times \frac{1}{54} \times 3.968$$

$$= 8{,}200{,}000\ \text{Btu}$$

where

ΔH = heat of reaction

453.6 = gm/lb

123 = heat of reaction, Kcal/mole of OF_2

$\frac{1}{54}$ = 1 mole per 54 gms

3.968 = Btu/Kcal

The values used are the heats of formation of OF_2 and H_2O in the standard state and the $Ca(OH)_2$ and CaF_2 are for high dilution, over 200 moles H_2O per mole compound.

To keep the final temperature below boiling, a very large amount of solution is required to absorb 2,000 pounds of OF_2. Starting with a solution at 100° F and heating to 200° F requires:

$$\frac{8{,}200{,}000\ \text{Btu}}{(200-100) \times 8.3} \cong 10{,}000\ \text{gallons}$$

This seems undesirably large, though not unmanageable. These results assume complete reaction and mixing. Actually some of the water will exceed the boiling point and vaporize, so less will be needed. On the other hand, the rate at which OF_2 can be absorbed by NaOH is not definitely known. We recommend lime, $Ca(OH)_2$, instead of sodium hydroxide, NaOH, because it costs much less and the reaction product is insoluble CaF_2, not soluble and toxic NaF. Reference 26 supports this choice, "five to ten percent solutions of caustic soda render fluorine gas completely harmess, providing the contact time between the gas and liquid exceeds one minute."

6.1.3 B_2H_6 DISPOSAL CONCEPTS. Diborane can be pyrophoric in air if any of the following conditions exist:

1. T > 293° F
2. IGNITION SOURCE
3. H_2O REACTION
4. OF_2 LEAK

Then:

$$B_2H_6 + 3O_2 \rightarrow B_2O_3 + 3H_2O + 31,100 \text{ Btu/lb}$$

Diborane disposal by burning would produce relatively harmless B_2O_3. Propane burner devices can be effective. Such a unit would consist of a burner stack, propane supply and control system, and an air blower. Liquid propane would be stored in a commercial tank, followed by vaporizors and accumulators. Blowers will supply aspirators in the burner stack. A water scrubber unit would be cut into the system for large quantities. Diborane is completely hydrolyzed by water:

$$B_2H_6 + 6H_2O \rightarrow 2B(OH)_3 + 6H_2$$

A dilute lime solution would not alter the basic reaction;

$$B_2H_6 + 3H_2O + 2Ca(OH)_2 \rightarrow B_2O_3 + CaO + Ca(BO_2)_2 + 6H_2\text{--etc}$$

Ten percent solution ammonium hydroxide NH_4OH has been recommended by Rocketdyne and RMD as a neutralizer (really a "knock down" agent). The hydrogen evolved is not toxic, but still should be burned off to avoid fire and explosion hazard. The water-diborane reaction can be explosive. The H_2 evolved can be a fire hazard.

Due to their hypergolicity, it would not be advisable to duct leakage from both propellants to a common disposal. While the chemical bath neutralizer can be effective, we recommend the burner disposal for diborane.

6.1.4 FEASIBLE DISPOSAL SYSTEMS. Table 6-2 compares the various techniques available. Some combination of scrubbing with a dilute lime solution plus burning appears to be feasible. Figures 6-3 and 6-4 show a conceptual OF_2 disposal unit. A typical input of dilute OF_2 vapor is reacted in a water fog shower chamber. The effluent product gases are further reacted and washed in an alkaline solution and then allowed to exhaust to atmosphere. This reaction should be checked experimentally. If it is inefficient, hot water or a catalyst would ensure a smooth start.

Diborane can be disposed of safely in a propane burner. Larger amounts will require a scrubber on the burner exhaust.

Table 6-2. Comparison of Propellant Vapor Disposal Techniques

Neutralizer	OF_2 or FLOX Disposal	B_2H_6 Disposal
1. Charcoal bed	Partial reaction, slow, bulky, hot	OK only as small absorber
2. Propane burner	No: HF product also toxic	Recommended, plus wash
3. Water, fog or spray bath	No: react to HF possible explosion	React, evolve H_2 potential explosion
4. Sodium hydroxide NaOH (caustic soda)	No: NaF partly soluble + toxic	
5. Ammonium hydroxide NH_4OH	No: NH_4F soluble + toxic	OK
6. Dry sodium carbonate Na_2CO_3	Slow, messy, 50% effective	
7. Lime solution $Ca(OH)_2$	Recommended	Slow, H_2 evolved so must keep out O_2
8. Activated alumina with soda lime	Absorbent	Absorbent

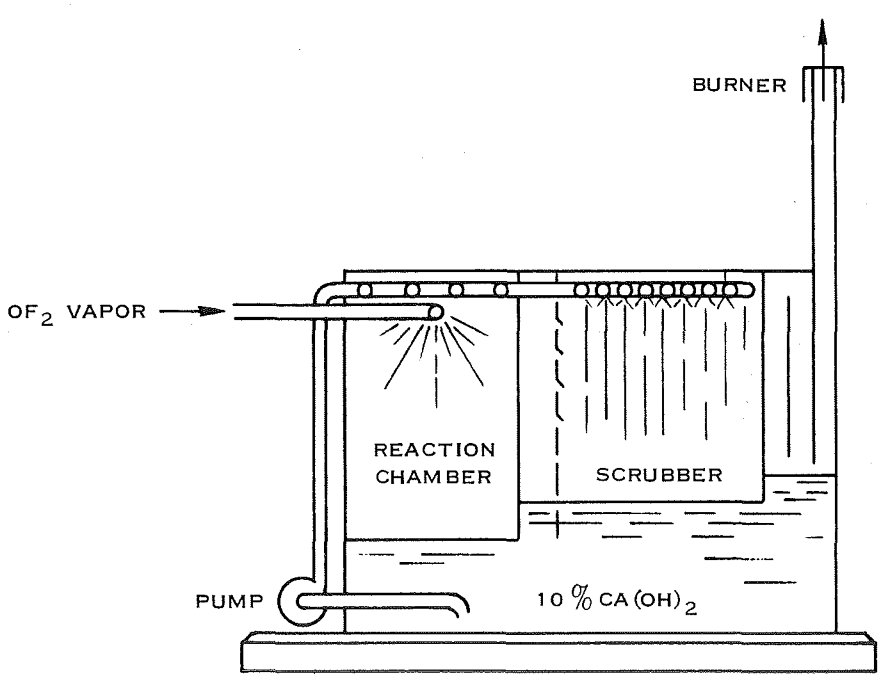


Figure 6-3. Conceptual OF_2 Disposal Unit

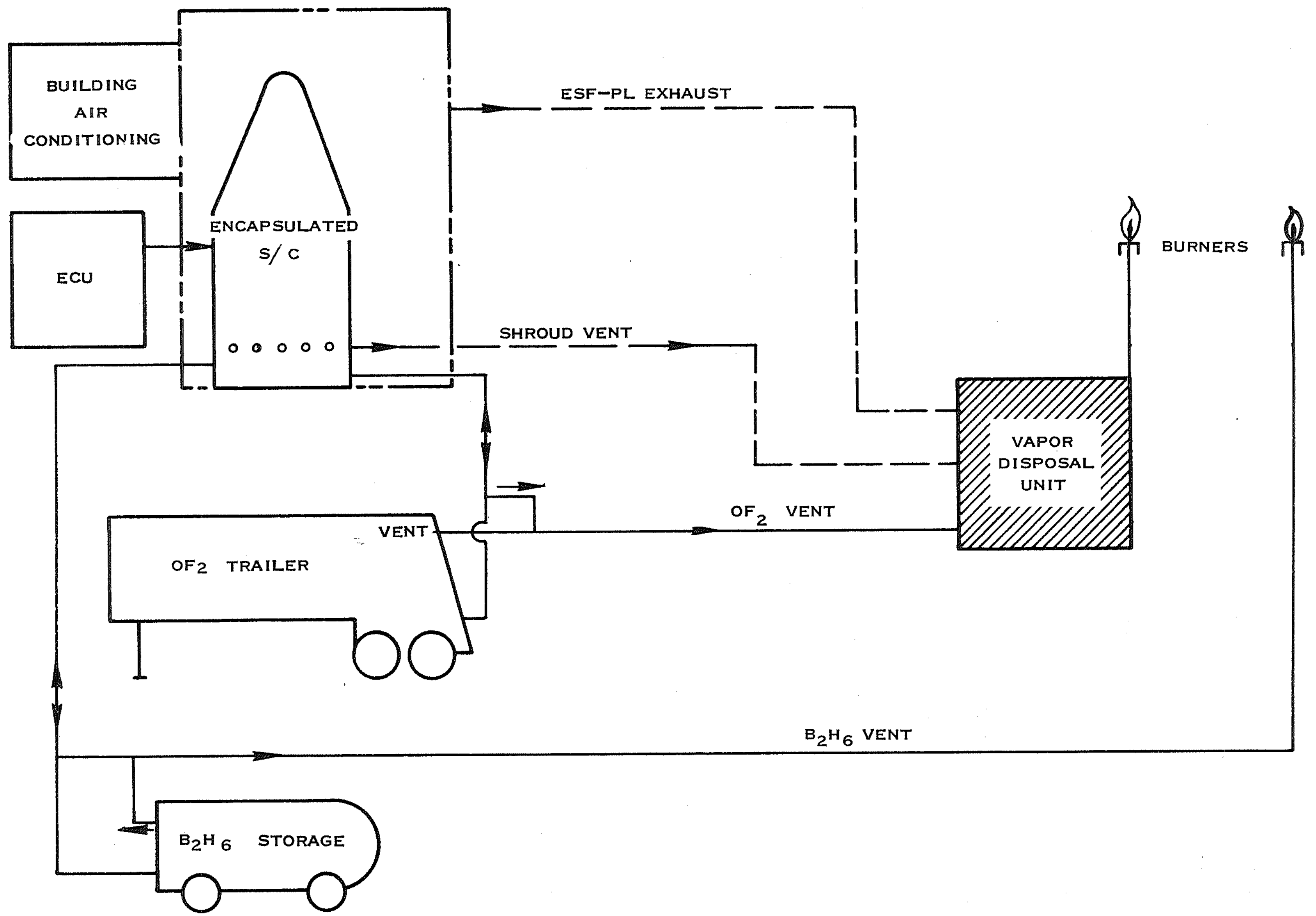


Figure 6-4. Vent, Leakage and Spill Disposal System

Approximately double the required solution is circulated by pump from the sump to fog/spray nozzles in the reaction chamber and scrubber. Internal baffles force the effluent through the scrubber. The propane stack burner will finally dispose of any H_2, or HF which is not absorbed into solution.

It is impractical to combine the functions of a leakage disposal unit and emergency drain receiver. The latter function can best be served by LN_2 shrouded dewars which would be much less cumbersome than a 10,000 gallon disposal unit, two of which would probably be required, one for each propellant.

The VDU can be sized smaller to dispose of 15 pounds OF_2 plus 4 pounds B_2H_6 with a 200 percent pad. About 100 gallons of 10 percent $Ca(OH)_2$ solution is needed, keeping the size reasonable. The unit can be mobile to accompany the caravan, or a larger permanent installation to handle air conditioning exhaust from the Propellant Lab.

6.2 SPACECRAFT ENVIRONMENTAL CONTROL

The environment of encapsulated spacecraft is controlled for several reasons:

1. Temperature - Air conditioning inside the shroud controls spacecraft temperature. Otherwise high temperatures could result from sunshine on the closed volume plus heat generated by payload prelaunch operations, especially if it has a Radioisotope Thermoelectric Generator (RTG) power supply. Or cold temperatures could occur at night or due to the Centaur liquid hydrogen tank loaded just a few feet below the spacecraft. A temperature of 85 ± 5°F was maintained on the Surveyor mainly for conditioning the solid propellant retromotor. For '69 and '71 Mariner Mars, bulk gas temperature within the nose fairing is maintained at 65 ± 5°F or 75 ± 5°F (optional choice at start of countdown) at all times that the spacecraft is mated to the launch vehicle. Reference 28 tentatively sets the 1975 Viking requirement at 55 ± 5°F.

2. Cleanliness - All equipment used in the encapsulation operation is thoroughly cleaned at the Explosive Safe Facility using techniques such as vacuum cleaning, wipe-down, and air purging in accordance with approved procedures. Cleanliness is maintained by filtering the incoming media, even approaching "sterile" level. The ground air conditioning ducts for Surveyor include 0.3μ filters. For '69 and '71 Mariner Mars, 99.9 percent efficient 10μ filters were installed. Covers are provided for each of the thermal bulkhead exhaust ports to maintain cleanliness during transport to the launch pad and during mating operations with the Centaur. It is intended that the nose fairing cavity be purged and maintained at a slightly positive pressure during the transport phase to maintain cleanliness. The cleanliness requirement is intended to preclude spacecraft operational problems which could be caused by dirt on lenses, radiators, antennas, etc.

3. Humidity - Humidity is kept low to prevent condensation, which would cause corrosion. Fifty percent relative humidity for air and dew point not to exceed 45 degrees for gaseous nitrogen are standard values. A dew point as low as 0°F is impractical with air, but -60°F dew point is reasonable with vaporized LN_2.

4. Reactivity - Inert media is used whenever LH_2 from the Centaur is present to eliminate fire and explosion hazard in case of a hydrogen leak or vented vapor drift.

5. Sterilization - To avoid contamination of planetary environment, all forms of life are sterilized by processing Lander portions in heat and toxic environmental ovens, then sealing prior to assembly with the rest of the spacecraft. It is not planned to attempt sterilization of the planetary orbiter nor its propulsion module.

An RTG will give off heat continuously from time of first installation. Depending on the spacecraft and mission, the RTG may be large enough to emit 500 - 2500 watts. This heat must be dissipated, especially after spacecraft encapsulation, with some form of air conditioning. Cold water chilling has been proposed for the 1200 watt RTG in the Lander capsule of the 1975 Viking.

The proposed Standard Centaur shroud for Viking will be of aluminum construction, and may need insulation blankets inside to keep the temperature down facing the spacecraft. There will be a thermal bulkhead across the field joint separating the payload compartment from the Centaur forward electronics compartment. Inside the shroud there will be air conditioning distribution ducts with nozzles and outlet orifices tailored to impinge on particular hot or cold spots on the spacecraft. These ducts are redesigned and usually require flow checking and temperature testing for each new payload. A typical arrangement is shown in Figure 6-5.

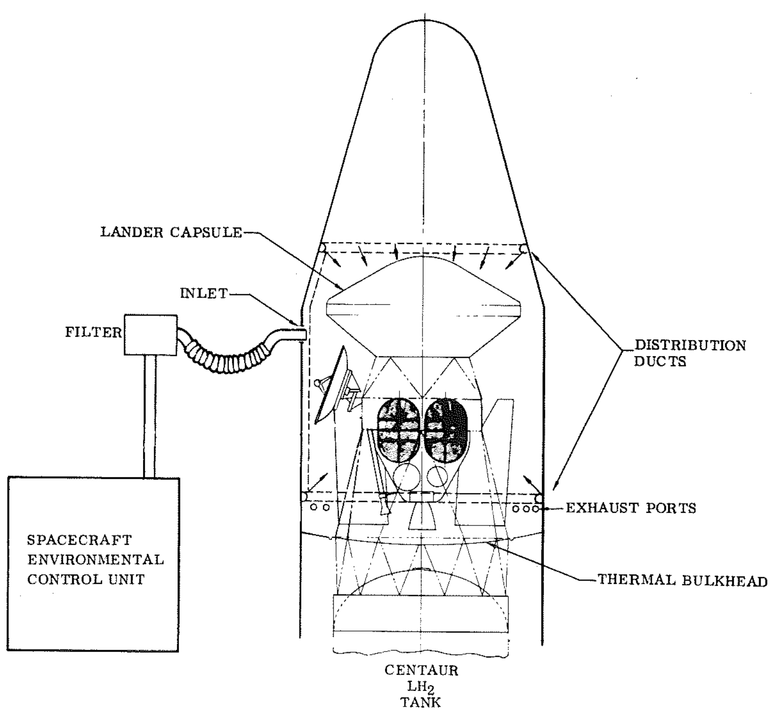


Figure 6-5. Typical Environmental Control System Arrangement

The air conditioning flow enters the nose fairing through a large ~ eight-inch diameter inlet closed after launch by a flapper door. A slight positive pressure is maintained in the shroud, approximately two inches of water. The air conditioning is exhausted and the entire shroud volume vented during ascent through about 30 vent ducts approximately one inch diameter, located carefully with respect to ascent aerodynamic pressure distribution so as to maintain slight internal pressure.

It is reasonable then, to assume that planetary spacecraft of the future launched by Titan-Centaur boosters will require similar environmental control. The temperature, flow rate, and sequencing may vary with particular spacecraft requirements, but may nominally be:

Spacecraft Environmental Control Parameters:

1,000 cfm or 75 pounds/minute

55° F to 80° F thermal control range with 40° F to 110° F ambient

40 degree dew point maximum

20 inch H_2O pressure at disconnect, filtered to less than 10 μ

Air and GN_2 capability

An important environmental consideration is to preclude atmospheric frost or ice build-up on a space storable propellant tank. If GN_2 is used for environmental control whenever the space storable propellants have been loaded in the propulsion module, no frost could build up, and the inert atmosphere discourages fires if any leaks occur. Vaporized LN_2 provides a ready source of GN_2 which assures an extremely low moisture content. If the Propulsion Module is tanked at the launch site during final countdown, GN_2 purge will be used. It is impractical, however, to maintain 75 pounds/minute GN_2 flow continuously from encapsulation to launch for the case where tanking occurs in the ESF.

A mobile environmental control unit is required away from the launch pad to maintain cleanliness by positive pressure, for cooling during electromechanical checkouts, and also temperature stabilization if the propulsion module is tanked. Using GN_2 is impractical for extended periods and while in caravan between the ESF and Complex 41. At 75 pounds/hour, 16,500 gallons of LN_2 would be used per day. Therefore air would be used in caravan. At a dew point of 45° F, air contains 0.006 pounds water/pound of air, consequently an insulation purge is required to prevent frost accumulation on an exposed space storable propellant part.

Such air conditioning units consume a great deal of power, usually 440v for the compressor, as much as 150 kva total. This then necessitates a power supply accompany the unit in caravan.

In summary, then, an Environmental Control system will be required all the time the spacecraft is encapsulated. At the launch pad, a substantial unit rated at about 1,000 cfm is required. If the propulsion module is loaded with space storable propellants in the ESF, a large capacity air conditioning unit must be mobile, supporting the spacecraft in the ESF and enroute to Complex 41. If the propulsion module is loaded at Complex 41, a lesser capacity purge would suffice in the ESF and caravan. It is possible that the 1975 Viking ground air conditioning units could be utilized for a space storable propulsion module.

6.3 FACILITY REQUIREMENTS

Table 6-3 lists various facility requirements necessary to accommodate the ground equipment. Some items such as the CRES floor in the Propellant Lab were discussed during visits to the KSC/ETR sites.

Table 6-3. New KSC/ETR Facility Requirements

	If Load at ESF		Load at
	Prop. Lab.	Assy. Bldg.	Complex 41
Modify Building Air Conditioning	X	X	
New CRES Floor	X		
New Propellant Storage Area	X		X
OSE Installation Area	X		X
Weather Measuring Equipment	X		Existing
Mobile Propellant TCU	X	X	X
Emergency Drain Provisions	X	X	X
Special Fire Fighting System	X	X	X
Special Weighing System	Existing	Existing	X

6.4 COMPONENTS

Particulate contamination and moisture level in the propellant system will have to be carefully reduced to a very low level. It is normal practice at KSC/ETR to use molecular sieves or other techniques to keep the moisture content in helium and nitrogen gases as low as 2 ppm. Such dry gases are used in the Thor and Saturn S-IVB propellant systems to purge/dry below a specified limit of 200 ppm moisture. Sintered nickel particulant filters, labyrinth and stacked disk types, have been found satisfactory. Therefore, we find no new or unique requirements for moisture and contaminant levels but rather tight, careful application of current practice.

Only Annin valves with teflon chevron packing are used by Rocketdyne at their Reno, Nevada, test site. No plumbing leaks have occurred, although the teflon packing in the Annin valves does have to be tightened occasionally. JPL has had trouble with galling at ERB with electropolished CRES B-nuts, with no lubricant; Rocketdyne has had no galling problems with standard fittings, using no lubricant. Lines are stainless steel, 1/4 inch to 1/2 inch for transfer. B-nuts are installed with copper conoseals.

As shown in Figure 6-6, three types of propellant lines can be used. A bare pipe is economical and useful for short transfer lines where heat losses are not critical. Foam insulated lines reduce propellant heating after initial chilldown, but they are more expensive to install and maintain. Foam is recommended with B_2H_6, but not near joints in an OF_2 line because of compatibility problems in case of a leak. In a triple wall line, the LN_2 blocks all heat into the OF_2 propellant. The vacuum system grossly increases initial costs. Initial chilldown is very fast, which would be important in an emergency drain situation.

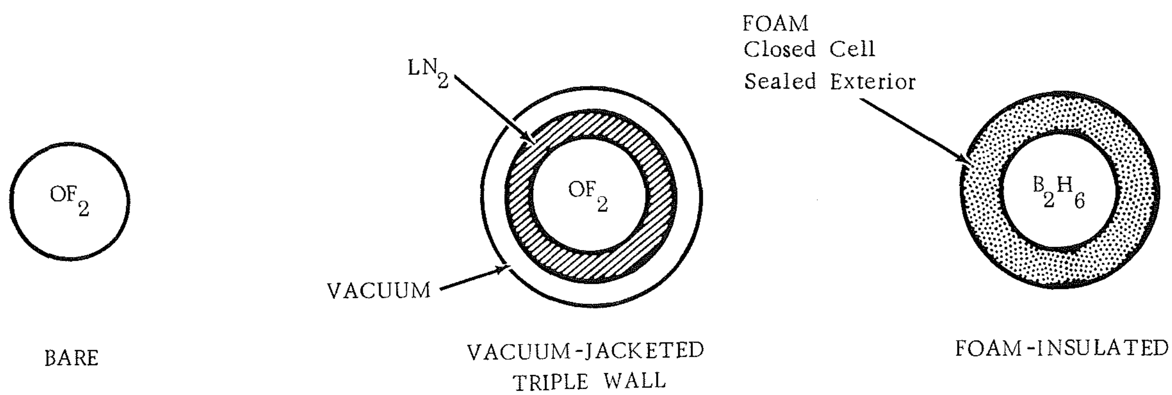


Figure 6-6. Types of Propellant Lines

7

FLIGHT VEHICLE CONSTRAINTS

What difference will it make in propulsion module tank safety factors if space storable propellants are loaded in the ESF thirty days before launch instead of at Complex 41 during launch countdown? Will the earlier tanking necessitate grossly heavier tanks to comply with pad safety regulations? Are there integrated airborne and ground system designs which can provide propellant thermal control with no frost on the propulsion module tanks? Should an access door be provided in the nose fairing to allow manual servicing of the spacecraft? It is valuable to study such ground-airborne system interrelationships very early in the spacecraft conceptual design phase, and to keep them in mind throughout the program.

First it is beneficial to review the following list of flight vehicle design features which may be constrained by the cryogenic, toxic, and reactive nature of space storable propellants.

The cryogenic nature of the propellants causes:

1. Thermal conditioning to avoid boiloff or vent.
2. Potential overpressure problem which requires relief or margin.
3. Limited material selection.
4. GN_2 or helium purge for frost prevention.
5. Tanks thermally isolated from structure, engine, and RTG.

The toxic nature of the propellants causes:

1. Closed propellant systems drain and purge before repair.
2. Vent or drain connection to safe vapor disposal.
3. Recommendation for disarmed propellant valves.
4. Minimum handling connections.
5. Hazard sensing systems, inside shroud and outside.

The reactive nature of the oxidizers causes:

1. Limited material selection.
2. Effective moisture purge and drying.

3. Explosion proof electrical and electronic equipment.

4. Excellent sealing (B_2H_6 leaks $\gg$ MMH).

5. $B_2H_6 < 70°F$ to preclude decomposition (Figure B-7).

6. Compatible propellant system insulation.

7.1 PROPELLANT THERMAL CONDITIONING

The spacecraft and ground support systems must be carefully integrated for propellant thermal control. Obviously, a heat exchanger system with coolant recirculation requires two ground to air disconnects, while only one inlet line would be required if the tanks were cooled by LN_2 evaporation.

At first it would seem advantageous to freeze the fuel to reduce its vapor pressure and to reduce the toxicity hazard virtually to zero. But the solid or slush propellant might not warm up sufficiently to support mid-course correction.

Prevention of frost on the propellant system is a combined function of the moisture in the shroud environmental control medium, which uses GN_2 in the terminal countdown, and the temperature differential across the tanks insulation. Superinsulation systems for cryogens normally use helium or GN_2 purge to remove moisture, prevent frost and avoid cryopumping. Purge pins and gas distribution systems have been successfully demonstrated on liquid hydrogen superinsulation systems.

7.1.1 INSULATION SYSTEMS MATERIAL COMPATIBILITY. Insulation systems will impose a severe design restriction for use on fluorine systems. Most presently used insulating materials are not compatible with fluorine oxidizers. The specific compatibility with OF_2, however, has not been studied thoroughly. We can nevertheless predict degradative reactions with Perlite, Mylar, and foam type insulating compounds under many possible prelaunch conditions.

The Perlites are silica containing minerals as is fiberglass. The reason glass is etched and dissolved by HF and not other acids is that volatile SiF_4 is formed and escapes. This leads to complete reaction in a forward direction. Pure fluroine is easily contained in glass tubes if moisture is carefully excluded. Without this careful exclusion of moisture, Perlite will not be compatible or useful as an insulator.

Organic materials and the adhesives, fasteners, flocking agents, etc., which must be used in Superinsulation, can be fluorinated. These fluorinations occur with great rapidity and evolution of heat. Any resistance which these materials appear to possess is not exhibited for long periods of time. The organics and foams tend to soak-up the fluorine materials so that friction or impact may cause them to ignite. The products resulting from tests at Convair have been found to absorb the oxidant and gain weight. They also may "liquefy" and become gummy or granular. The apparent compatibility of a silicone polymer when dropped into liquid fluorine was disproved when the sample burst into flames after it was removed and allowed to warm up. If no moisture is present, aluminized Mylar exhibits a resistance but it is fleeting. Any hint of moisture causes loss of the aluminum film to HF reaction and Mylar degradation. Under space conditions of very little moisture, low temperature, and high vacuum, a system using aluminized Mylar could be useful.

Polyurethane foams have been used on Centaur and Saturn vehicles to insulate cryogens from the atmosphere. Porous foam for insulating space storable propellants has been analyzed in Reference 29. Closed cell foams with moisture barrier on the exterior and honeycomb sealed on the end faces have been used. But Reference 30 indicates these foams may react or burn with fluorine compounds under some conditions.

This type of behavior suggests that a study would be required before any insulating material could be qualified for a fluorine oxidizer system. Not only should samples of the materials be tested, but also the arrangement under representative ambient conditions from ground to space, considering system purges, vent passages, etc.

7.1.2 FLEXIBLE DESIGN ARRANGEMENTS. The fact that the space storable propellants are to be at or near the same temperature (in this case 250^{+30}_{-40}°R) immediately suggests thermal coupling of the tanks. There should not be a need to thermally isolate the fuel and oxidizer tanks from each other. There should not even be a need for a radiation shield between tanks. Conductive straps between the tanks may be desirable to minimize differences which might result from one tank being more exposed to solar radiation, planetary albedo, or engine radiation than the other tank.

Theoretically, this allows a side range of geometric arrangements including concentric tanks, a torus around a cylinder and even a common bulkhead; see Figure 7-1. Such configurations may have advantages for meteorite protection, envelope packaging, center of gravity, etc. These may result in weight savings. Obviously some such arrangements are critically sensitive to leakage.

The common temperature allows great flexibility in location of the pressurant (probably helium) supply. A pressurant storage temperature of approximate 220°R can be obtained by locating the supply inside either propellant tank or outside but thermally shorted to either tank.

The multiple possible thermal packaging concepts of the tanks and pressurization bottles allow flexibility of prelaunch sequences for loading. In any case, the prelaunch sequences for loading. In any case, the prelaunch thermal conditioning system will probably be activated first, then either propellant or the pressurant could be loaded next. Other considerations might dictate sequence (such as the 24 hours desired for OF_2 system passivation), but <u>thermally</u> the sequence is not restricted.

7.2 PURGE AND PASSIVATION

Probably the most extreme or crucial design constraint is caused by the reactivity of a fluorinated oxidizer. Obviously a substantial reaction in this propellant system will destroy the spacecraft. Even though compatible materials have been selected, prelaunch operations must not jeopardize the system. There have been numerous histories of fluorine or FLOX systems which experienced catastrophic reactions after several - even more than twenty - successful operations. It is mandatory that all prelaunch operations be conducted with meticulous care to avoid contamination. Purging, drying, and passivating procedures must assure compatibility. Aside from material contaminants, moisture is the greatest hazard. Not only is the oxidizer involved, but unlike most fuels, diborane reacts with water and may be pyrophoric. Propulsion module propellant lines must be designed for perfect drying. This means no traps, low points, pockets or faying surfaces to collect moisture. It is generally felt that thin sections such as bellows are particularly susceptible to burn-through.

It would be extremely desirable to have operable engine valves which can be cycled open prior to propellant loading for complete purge. If the engine valves are sealed or deactivated during ground operations to preclude inadvertent propellant dump, then the fill line or a separate purge line must enter the feed line just upstream from the engine valve. See Figure 7-2.

All materials for containing fluorine oxidizers must be passivated. The passivation process consists of producing a film of fluoride compound on the surface of the material, normally a metal or alloy. This fluoride film is formed by exposing the contact surfaces to low concentrations of gaseous fluorine compound diluted by inert gas. The concentration is then increased by reducing the quantity of diluent and then increasing the pressure.

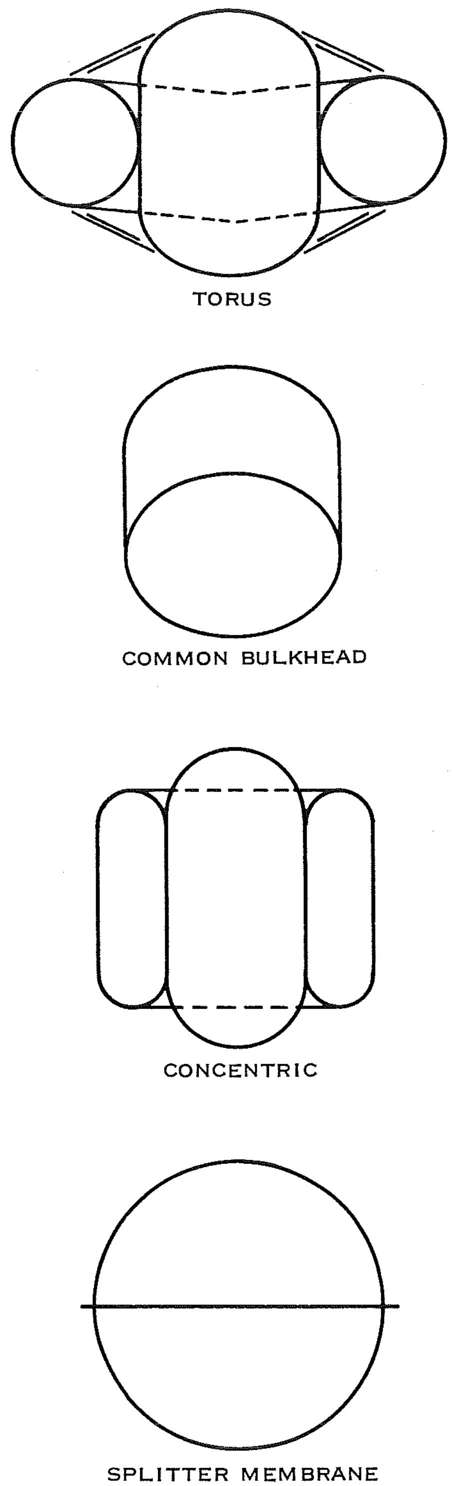


Figure 7-1. Possible Space Storable Propellant Tank Arrangements

The film of fluoride serves two purposes. First it forms a hard surface which is inert to the liquid oxidizer which will contact it. Second, if any impurity is present, the heat of reaction of the partly fluorinated materials is substantially reduced so that if any rapid reaction should occur it should not lead to a combustive type burnout reaction.

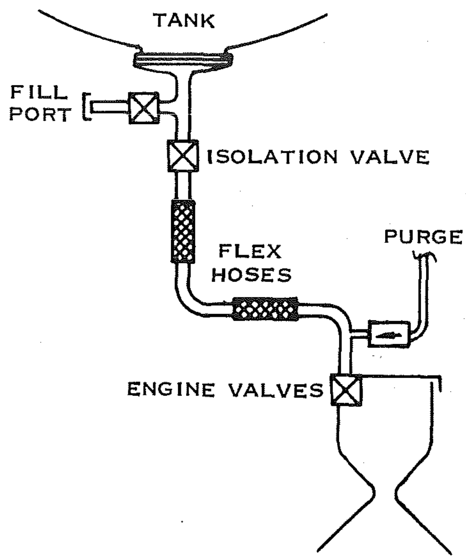


Figure 7-2. Possible Feed System Purge Configuration

Improper care of a passivated system increases the possibility of failures. This is because fluoride films are generally hygroscopic. They tend to react with water if care is not taken to keep out moisture. A new surface replaces the tough, hard, inert and adherent fluoride film. The new surface, consisting of oxy- and hydroxy halides mixed with hydrogen fluoride, is loosely bound, readily removed and leads to erosion pitting and other signs of corrosion. This can be disastrous if the surface composes a sealing surface. Furthermore, the HF which is formed is itself hygroscopic and acidic, so that acidic type reactions like metal solution occur. The residues of this reaction can form additional salt-like, gelatinous, gummy encrustations or deposits which tend to cement moving components or cause them to malfunction. It is therefore important not only to passivate a fluorine oxidizer system but also to keep it clean and dry.

7.3 SEALING

All propellant and pressurization systems must be designed and built leak-tight. The cryogenic, toxic, and reactive nature of the propellants make leaks extremely hazardous. The long duration of the planetary missions - 220 days to Mars, about 550 days to Jupiter, and nearly four years to Saturn - means that even a small leak could vent off a significant portion of propellant. In space, the torque created by such a leak-jet would perturb the spacecraft, causing consumption of attitude control propellants. For these several reasons, leak-tight propellant systems are even more critical than on existing launch vehicle upper stages. Approval of ground operations with a loaded propellant module may hinge on demonstrated sealing excellence.

These critically tight leakage requirements will constrain propellant tankage design by dictating minimum joints and openings. Tank midriff flanges are to be discouraged. Small top and bottom ports, more like those on a helium bottle, are recommended. Most, preferably all, joints should be butt welded, even where the feed line attaches to the tank. Note that system drying and purging procedures usually involve evacuating the lines, so the joints must be vacuum tight.

Typical leakage criteria including mass and pressure loss, spacecraft perturbation, and even formation of a crystal visible to the star tracker are discussed in Reference 31. Typical leakage limits range from 10^{-2} to 10^{-9} scc/sec. The report states that "the most critical problem area (in advanced valve technology) is that of leakage". "Calculating the worst case total leakage allowance . . . . will usually result in very low individual (path) leakage allowables that are often beyond the state of the art" (in both design and test).

Extremely reliable, tight sealing valves will be a major challenge of the propellant system development. Pyrotechnic valves present problems for fluorinated oxidizers because blowby or heating could trigger a reaction. Solenoids or pressure operated valves, to control propellant flow with virtually zero leakage, must be developed. A special problem exists in the engine shutoff valve: after the engine has been hot fired or cold flowed, the downstream portions of the valve will be passivated with a fluoride. If these surfaces are ever exposed to atmosphere with moisture, reactions will occur, producing powders and gels which may prevent proper function. Should the thrust chamber be positively sealed with a blowout plug throughout until the next firing, midcourse correction in space? Or should the valve be removed and recleaned, invalidating the firing?

7.4 SPACECRAFT TO GROUND DISCONNECTS

Existing Centaur nose fairings provide no access to spacecraft once encapsulated. Surveyor and Mariner type spacecraft have been designed for filling and charging in the ESF prior to encapsulation. Therefore, all connection points such as fill disconnects were close coupled into the spacecraft, manually accessible only with the spacecraft sitting on the floor of the Propellant Lab. In order to provide access on the launch pad for loading, thermal control, hazard sensing, and/or emergency drain or vent, there will be some increase in spacecraft and launch vehicle complexity and weight. Table 7-1 shows that the number of launch disconnects is between 3 and 23.

Table 7-1. Possible Launch Disconnects to Propulsion Module

1 or 2	Propellant thermal control - mandatory
1	Insulation purge - mandatory
1 or 2	Environmental control - mandatory, shroud only
1 or 2	Hazard sensing
1	B_2H_6 fill and drain, evacuate & purge
1	OF_2 fill and drain, evacuate & purge
1	B_2H_6 pressurization and vent
1	OF_2 pressurization and vent
1	Helium charge and vent
0 - 4	Propellant line purges
0 - 7	Pneumatic control lines
Total: 3 minimum, 23 maximum	

One design approach is to bring the disconnects out to the shroud skin line. This is complicated by the separation sequence. The shroud is jettisoned about three minutes after launch during Titan burn. Later after Centaur burnout, the entire spacecraft is separated from its structural adapter. Note also that there is a "field joint" to facilitate buildup in the tower. The spacecraft is encapsulated in the shroud portions forward of this joint.

Referring to Figure 7-3, a line such as thermal conditioning supply could enter the vehicle at the Centaur forward umbilical panel (1) with a launch disconnect. The line would need a manual coupling at the field joint (2) (probably flange and seal). There would be an external seal around the line as it penetrated the thermal bulkhead and then is routed forward up the payload structural adapter. There would have to be an inflight disconnect at the spacecraft mounting ring (3). This disconnect would require not only virtually perfect sealing but also repeatably smooth disconnections so as not to impart disturbances to the spacecraft at separation. Six such disconnects for either 1/4 inch or 1/2 inch line size may be required: a purge/passivate/fill/emergency drain and a purge/evacuate/pressurize/vent for each propellant tank, a helium charge line, and a thermal control line. Additional items are possible such as hazard sensing and purge. It is estimated that six such lines with joints, disconnects, insulation and supports would add about 10 pounds to the Centaur which is direct spacecraft weight loss. This approach, then, is heavy and complicates the spacecraft, but maintains thermal control and emergency drain right up to launch.

Manual access could be provided through large access doors in the shroud as is done for the Centaur forward electronics compartment. The weight trade-off is about 15 pounds of shroud to one pound payload. Estimating 40 pounds added by two such shroud access doors, the payload penalty is less than three pounds. The manual disconnects (4) on the spacecraft can be capped to assure they are leak tight. All lines would have to be disconnected and the doors closed before the mobile service tower is removed, or about eight hours before launch.

7.5 ACCESS TO PROPULSION MODULE

It has been past practice to completely seal the Surveyor and Mariner spacecraft. No access, not even hand holes, was provided in the nose fairing. The only concession to emergency access was a stencilled sign, "Cut here in case of emergency". We recommend that one and perhaps two access doors be provided in the standard Centaur shroud. Sized about 24 inches square, the door(s) would allow technicians access to the encapsulated spacecraft. Figure 7-4 shows such a door located at about Station 2600, above level 12 on the umbilical tower. To avoid damage to the spacecraft from undue handling and contamination from atmospheric dust and moisture, the door must be closed, perhaps locked, at all times except during a prelaunch operation. In other words, the access door must not become a view port for visiting VIPs, or it will reduce spacecraft reliability. Using the door for manual connections, emergency drain and pressurization connections can be made directly at a panel on the propulsion module without the

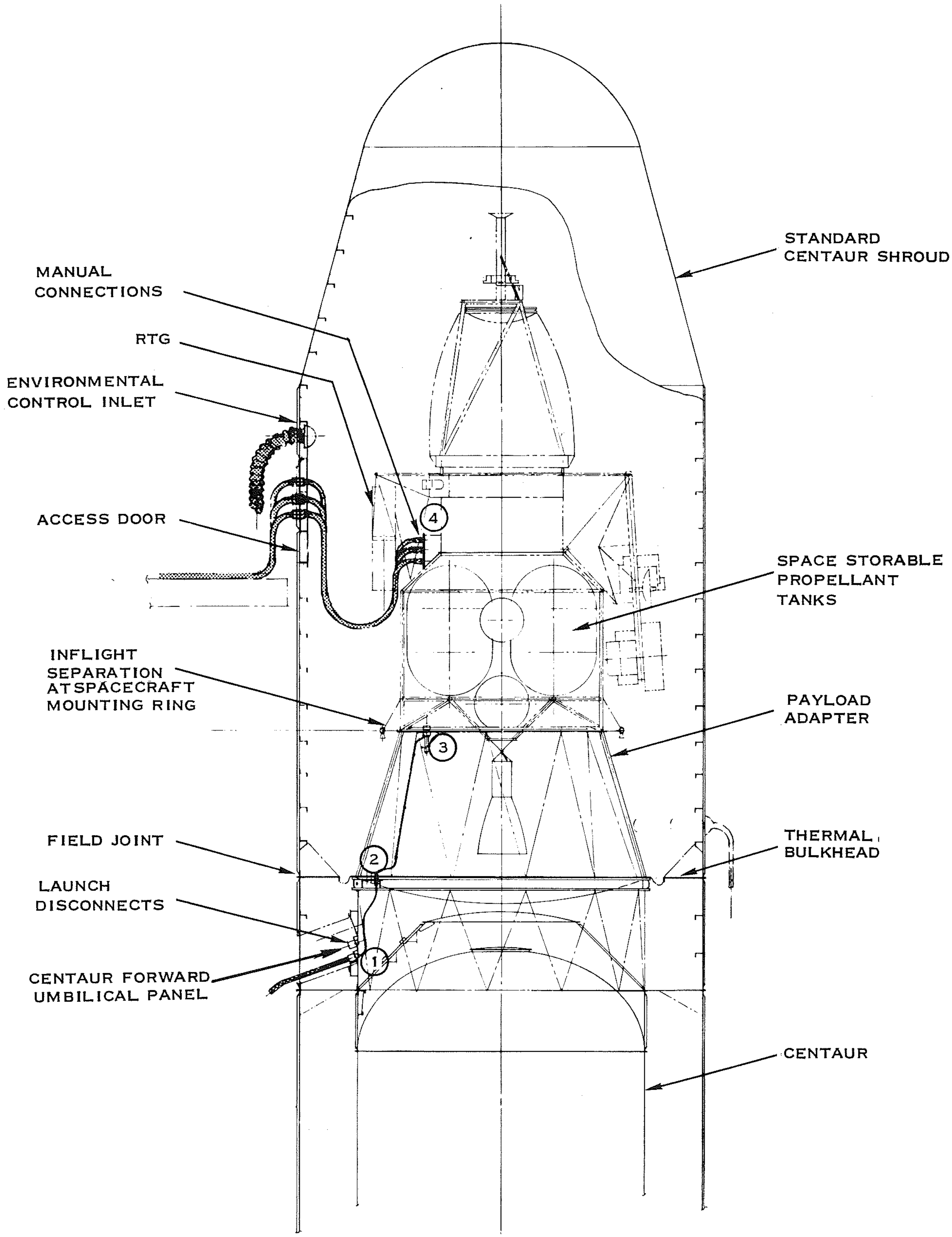
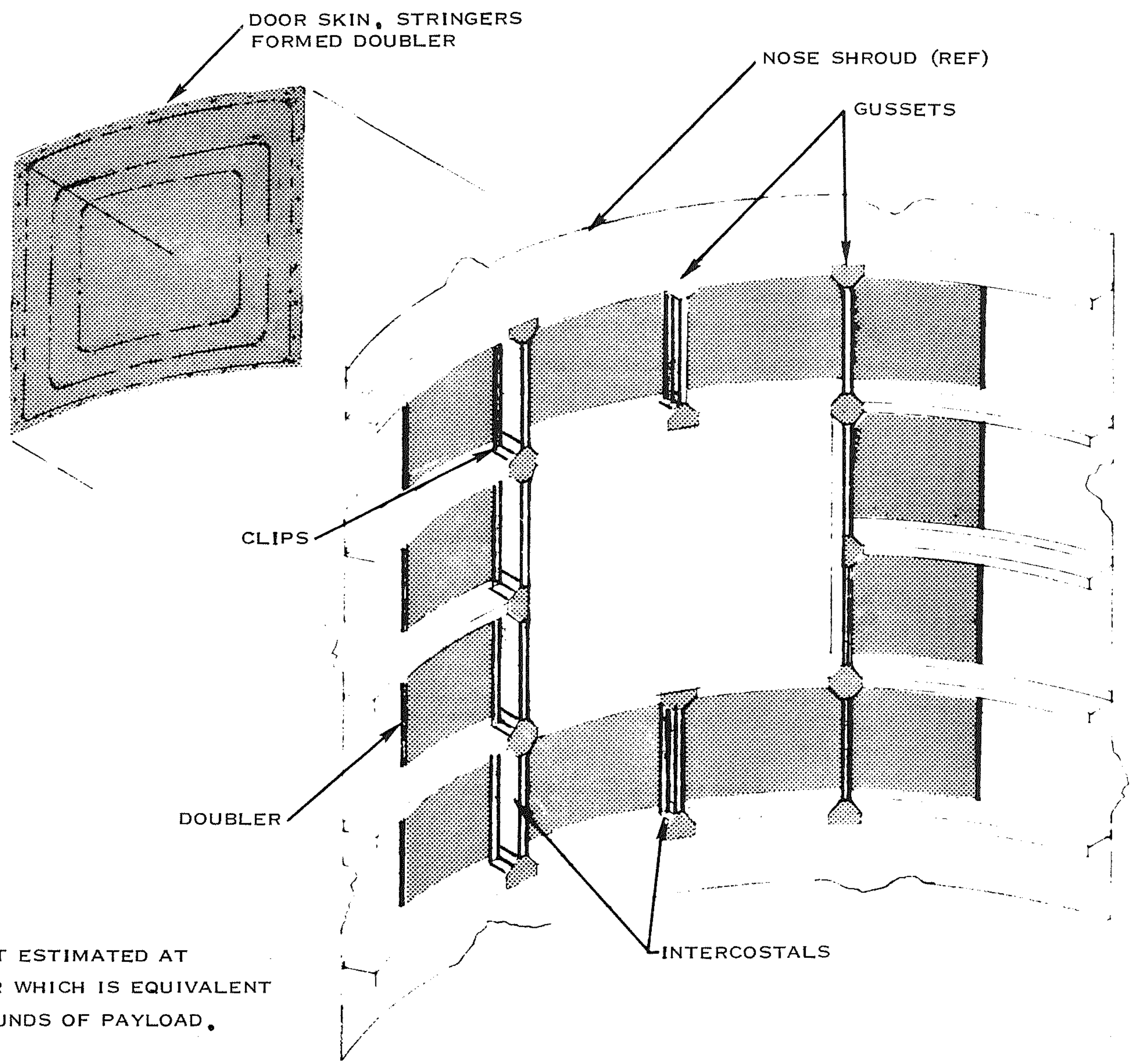


Figure 7-3. Propulsion System Disconnects on a Typical Outer Planet Spacecraft



NOTE:

TOTAL ADDED WEIGHT ESTIMATED AT 20 POUNDS PER DOOR WHICH IS EQUIVALENT TO LESS THAN $1\frac{1}{2}$ POUNDS OF PAYLOAD.

Figure 7-4. Access Door Arrangement in Standard Centaur Shroud weight and complexity of launch and in-flight disconnects. Temporary installations such as plastic bags for leak collection or direct vapor sensors may be made through the door. Eight hours before launch, these lines and test installations would be removed and the door sealed. It is reasonable to expect that reaction and leakage potentials should decrease as time elapses without any mishaps. After the system has rested statically for many days at the site without problems arising, chances of needing the emergency drain or vent are minimum during the last four hours before launch.

The spacecraft propulsion module such as shown for a Jupiter Orbiter will probably be about seven feet in diameter. Since the standard Centaur shroud is 14 feet for the Viking mission (and an S-IV shroud is about 260 inches in diameter), there is along reach from the shroud skin inboard to the spacecraft. This necessitates a large access door so that personnel can get their entire trunk inside and possibly an internal rest platform. Structural reinforcement of the shroud around the cutout, including doublers, plus the door are expected to add less than 45 pounds to the shroud, which is equivalent to three pounds of payload.

7.6 RTG INSTALLATION

Handling the Radioisotope Thermoelectric Generators (RTG) is interrelated to the propellant handling in several ways:

1. Personnel safety.
2. Heat transfer.
3. Access.

Both in the case of the RTG and with toxic propellants, all personnel with access to the site must wear badges to show they have had the necessary safety training. These badges will limit the number of persons allowed in the service tower and be even more restrictive in the vicinity of the payload itself. As the Atlas-Centaur-Pioneer F is currently planned for 1972, the four RTG units will be installed about one day before launch. Technicians making the installation will be limited in allowable exposure time close to the unit, so teams may have to work in rotation to complete the six hour job.

Convair is beginning a study effort for LeRC and the AEC to define launch vehicle explosion/failure possibilities with RTG units so that a Safety Analysis Report can be written by AEC-Sandia-Teledyne Isotopes which ultimately requires Presidential approval before launch.

Special air conditioning impinging on the RTG units is required to dissipate the 600 watts/unit output and avoid reaching the 270°F max unit temperature allowed. As high as 1,300 scfm cooling flow may be needed in the Centaur nose fairing. The RTGs obviously become a major heat source from which to insulate the cryogenic propellants, both on the ground and in space.

It is currently proposed to cut access doors in the OAO type fiberglass nose fairing for installation of the RTG's on Pioneer F. Therefore the access doors recommended for access to a Space Storable Propulsion Module would not be unique, and may possibly be combined with those for the RTG.

7.7 PROPULSION MODULE CHECKOUT

The high reliability of spacecraft and launch vehicles in recent years is due in part to comprehensive, meaningful final checkout tests shortly before launch. The accepted sequence is based on a large amount of data from development, qualification, and quality control tests. Parameters are established based on this data indicating ranges of acceptable function. For example, a propellant shutoff valve may be expected to open in 40 ± 10 milliseconds under ambient conditions. Experience has shown that if the valve is within these limits under checkout conditions, it is in good working order: the moving parts are not galled, springs are not fatigued, control orifices are not plugged, etc. Prior testing data has shown that the component that opens within 40 ± 10 ms ambient, has always opened properly for firing under flight conditions. Therefore functional tests are arranged to perform such an ambient time check before engine acceptance firing, again at engine sell off, prior to spacecraft installation, at spacecraft factory selloff, and in final checks at the launch site. Similar reasoning is applied to the ambient, low pressure leak tests which can be correlated to high pressure cryogenic use.

The reactive nature of OF_2 makes the above standard checkout somewhat less dependable. There is some small chance that the prelaunch loading of propellant or inadvertent introduction of moisture through a purge have caused valve deterioration. Pyrotechnic valves create several challenging problems connected with system arrangement for best prelaunch leak check and passivation. Normally open (N/O) valves are less critical than normally closed (N/C) valves to reaction at operation because they do not expose newly sheared surfaces to the reactive propellant. In all explosive valve arrangements it is difficult to clean and passivate both sides. Some valve designs cannot be high pressure leak tested but must be subjected to vacuum tests. Reference 31 recommends that "the N/O valves and the downstream side of the N/C valves be leak checked by measuring their ability to retain a vacuum condition and then passivated by bringing the pressure back to ambient with pure GF_2".

Therefore the design of the entire propulsion module should be constrained by checkout considerations. Electrical control logic should be scrutinized for any secondary "sneak circuit" signals which might inadvertently open a valve. What happens if a bus is unintentionally shorted? Where possible, design and procedural safeguards should be included such as deactivating or disarming key circuits, unless checkout or launch are in progress. Functional checkout capabilities must also be considered in a real effort to achieve the most meaningful check possible, as near launch as possible. Consideration may be given to running some checks in the cryogenic systems with LN_2 on board or possibly with the diborane frozen.

Some checkouts and purges may be accomplished with temporary connections through an access door or in-flight disconnects. Basically we do not recommend self sealing disconnects, but rather slip joints internally open with separate valves sealing the line in flight. It is vital that the line contain no propellant, nor even vapor at separation. The propellant module should be designed with separate line shutoff valves so that all propellant or vapor may be purged before separation. Referring to a typical schematic, Figure 7-5, the OF_2 fill and drain shutoff valve is located at the tank or feed line interface. After filling is complete, the valve is closed and the line alternately purged and evacuated, until dry. Then the sleeve type coupling may be disconnected manually with the line dry. When the disconnect is manual, the coupling may be capped to keep out contamination and to serve as a backup seal. This arrangement allows fuel and oxidizer disconnects to be grouped together for convenient panel arrangements, because they are dry when disconnecting.

7.8 PROPELLANT WEIGHING

The quantity of propellants loaded aboard the Propellant Module and the center of gravity of the flight-ready configuration must be known as accurately as possible. The question of when and where the weighing operations should be done is dependent on where the vehicle is tanked. Convenience, safety, and accuracy of the final result are factors considered to be important. One-half percent accuracy, or 12.5 pounds out of 2500 pounds, is expected.

Mechanical weighing on a scale is one of the easiest and most accurate methods of making the desired measurements. This can be done on the separate free-standing vehicle after it has been loaded with propellants and gives accurate weights for each propellant. This procedure corresponds to the final mass check on an Atlas booster prior to delivery wherein two weighings are made, the second of which is 45 degrees rotated from the first. This method furnished both mass and center of gravity information. Weighing in the ESF has been standard practice on Surveyor, Mariner, etc.

If the Propellant Module is tanked at the launch site, load cell measurements including the entire launch vehicle become too inaccurate. Weighing the propellant storage tank or mobile dewar before and after loading also involves serious inaccuracies due to the large tare, residuals in the fill lines, and the uncontrolled atmosphere. Fluid flowmeter readings involve other questionable parameters in calibration, two phase flow, residuals, etc.

The Centaur employs propellant level indicator probes inside the propellant tanks. These devices add spacecraft weight, tank penetrations, and compatibility problems. Nucleonic devices outside the tank are a possibility.

However, weighing can be done accurately and in place by using semiconductor wafer load cells (available from Koolite-Bytrex Company or "Strain Sert"). These are very

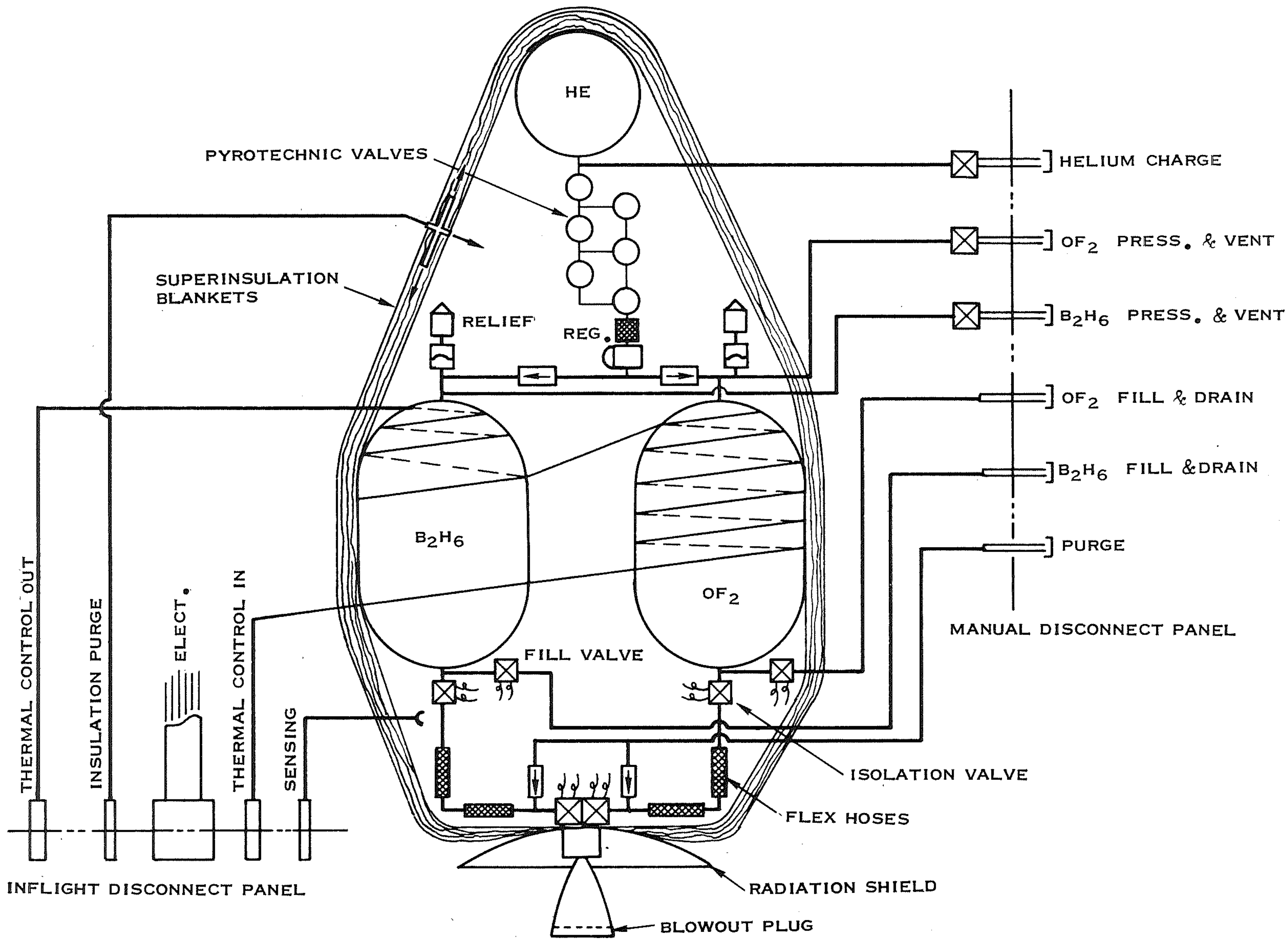


Figure 7-5. Manual and In-Flight Disconnects

accurate and do not distort like strain gages and are capable of an automatic electrical output. A unit can be placed at each load point between the Centaur and the Spacecraft (perhaps eight channels required) thus enabling both the weight and center of gravity determinations to be made easily. No connections or added load on the Spacecraft are necessary if the equipment is removed through the access door before launch.

7.9 HAZARD SENSING

As mentioned in Section 6.1, it may be desirable to monitor the exhaust from the shroud for evidence of leaks. The standard Centaur shroud provides a single large inlet door for spacecraft Environmental Control (air conditioning) and multiple small outlet vents. These exhaust ports must be located away from fairing contour changes so that smoothly decaying outside pressure is experienced in spite of aerodynamic turbulence during ascent. This allows the internal volume to vent steadily during boost maintaining a slightly positive pressure in the nose fairing. As discussed earlier in the ECU section of this report, it may be advisable to collect the exhaust from these ports at the launch site and sample for possible indication of propellant leakage. With corrugated shroud skin, it may be a real problem to install a reasonably tight plastic manifold over these ports. The ports could be temporarily closed with plastic caps and exhaust collected from a non-flight exit, perhaps in the fixture replacing the access door. Or this hazard sensing concept may have to be abandoned in favor of multiple sensors or manifolded sensing tubes located inside the shroud.

If the Propulsion Module is insulated in a relatively tight insulation-meteorite shield, it is preferable to sense inside this cocoon, as shown in Figure 7-5.

In these several ways, the Hazard Sensing System may constrain or interact with the Propulsion Module insulation and aerodynamic shroud designs.

7.10 VESSEL SAFETY FACTORS

The ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, is the basic pressure vessel safety code. The State of California, Division of Industrial Safety issues Unfired Pressure Vessel Safety Orders based on the ASME Boiler Code. The accepted factors of safety for these pressure vessels are 1 - 2 - 4 (proof and burst pressure are respectively 2 and 4 times operating pressure). These conservative factors are accepted for long life, multi-cycle applications including aircraft pressure vessels under MIL-P-5518. These criteria and often extended to ground equipment for missiles and spacecraft, but are unnecessarily conservative for limited cycle, carefully controlled flight tanks.

The Centaur Structural Design Criteria, Report No. GD/A-BTD65-011, requires design safety factors for pressure vessels which would be hazardous to personnel in the event of failure:

Yield: 1.67 x operating pressure

Burst: 2.0 x operating pressure

Operating, proof, and burst are analogous to limit, design yield, and design ultimate, respectively. These less conservative factors depend on qualification tests, X-ray inspection, certified welders, and other careful quality controls.

The ETR Safety Manual, Reference 24, requires similar safety factors of 1.5 and 2.0 for space vehicle propellant tanks and high pressure vessels. It also requires that "personnel must be evacuated for the first system pressurization at ETR, or the initial pressurization after modification or repair, and thereafter whenever initial pressurization levels (P = operating pressure or 50% of burst) are exceeded".

On pressure vessels non-hazardous to personnel in the event of failure, Convair designs to the lower factors of 1.33 and 1.67. This would include a pressure vessel charged or topped off only during tanking test or launch countdown when the site is evacuated.

Consider a helium sphere of titanium alloy, 6 aluminum - 4 vanadium, annealed. At room temperature this material has an ultimate tensile strength, F_{tu}, of 134,000 psi and a yield, F_{ty}, of 126,000 psi. The pressure vessel wall thickness would be set by the ultimate. Using a factor of safety of 2 compared to 1.67 would permit an operating stress of 67 ksi instead of 80 ksi. On this simplified basis the bottle designed for people nearby would be 16.7 percent heavier than the bottle never fully charged with people around. A 3000 psi sphere could be designed to 80 ksi operating, but never pressurized above 2,500 psi with personnel around.

The comparison is complicated by a number of other considerations. Safety factors may be more conservatively established when one takes into account the cryogenic, reactive, and toxic nature of OF_2 as compared with helium. Long term material corrosion allowances are very small, like 1.3 mil/yr (Reference 32), but are significant on the outer planet missions. Spalling from meteorite impacts should be avoided, perhaps dictating heavier walls, particularly on "balloon tanks".

On the other hand, the yield and ultimate strength of most tank materials improves at cryogenic temperatures, which adds a conservative factor if room temperature allowables are used. Ti-6Al-4Vn has an ultimate strength of 205 ksi at -300°F, nearly double that at room temperature. Although minimum weight is achieved with low temperature allowables, in reality this is often not a practical design basis. If low temperature allowables were used, this would mean that at no time during checkout and test could the tanks be exposed to operating pressures under ambient conditions. This becomes even more critical when it is considered that the pressurization system has not yet been established and may use warm temperature pressurant. For these reasons it is advisable to base the tank weights on room temperature allowables even though some weight penalty is incurred.

There is perhaps a unique situation with the space storable propellant tanks being used as a baseline in this study. Allowing a propellant temperature range of 210 to 280°R, with a launch pressure of 240 psi, considering tolerances in initial ullage and mid course burn outflow, etc., a design burst of 800 psi has tentatively been selected. Therefore, even at maximum launch pressure this propellant tank concept has a factor of 3.33, more than required by ETR safety. This concept also requires that the tanks withstand an internal vacuum as part of drying, purging, and loading procedures.

One way to circumvent a possible approval problem or weight penalty is to allow personnel around partially pressurized propellant and pressurant tanks, then bring them up to final launch pressure during the countdown. For instance, loaded space storable propellant tanks might be held at 100 psi for weeks as work progressed around them and raised to 240 at T-8 hours before launch. This final pressurization might be entirely remote after the MST was removed, or could be done remotely followed by manual disconnection of the hose just before the MST was rolled back.

In summary, then, airborne propellant and pressurant tanks would nominally have more conservative safety factors when personnel will work around them and therefore tend to be heavier than vessels pressurized only when people are evacuated. But each case is complicated by a number of special considerations. The usual approach is to complete the conceptual design based on spacecraft and flight considerations, then request approval to operate with these tanks. Industrial safety representatives from the States of California and Florida, from NASA and USAF will give the problem special consideration. Satisfactory compromises can be worked out based on quality assurance, operating safeguards, and test sequencing.

7.11 QUICK DEMATING FEATURES

Removing a mated spacecraft is a slow process usually involving removal of 300 to 600 bolts. On the proposed Viking-Centaur design, four access doors would first have to be removed in the Centaur forward equipment area. The 160 bolts would probably not be quick releasing "Camloc" type fasteners, but rather load-carrying "torque set" screws. The GSE handling torus is then attached to the fairing with about 24 bolts and the payload support arms inserted into sockets. To separate the payload adapter from the spacecraft another 12 bolts must be removed. Finally the 14-foot-diameter field joint in the shroud must be loosened by removing 200 to 400 bolts. The encapsulated spacecraft can now be lifted up with the handling sling, moved laterally using the overhead hoist, and lowered to the ground. Based on Surveyor experience, this is normally about an 8-hour task. For a space storable propulsion module, the task could be complicated by the requirement for technicians to wear "splash" suits with face masks and gloves, or if an RTG unit is used, the work may be slowed by rotating personnel.

There are a number of possible flight vehicle features which could be considered to speed up demating of a loaded spacecraft. Pneumatic screw drivers have not been allowed for fear of over-torquing the screws. If protective gloves are required, access to many joints would have to be enlarged. Marmon clamp type circumferential joints with just a few large hoop bolts tend to be heavy and subject to catastrophic failure. Camloc fasteners could be used with dowel pins carrying the load. For an emergency, a circumferential shaped charge to cut the field joint could be considered.

The complex, slow process of demating an encapsulated spacecraft has been accepted in the past. Regardless of the type of propellants used, it seems desirable to consider new design approaches to simplify and speed up removal of future spacecraft, most of which are increasingly valuable.

8

FLOX-METHANE

While the primary study effort centers on handling OF_2 amd B_2H_6 for a pressure-fed propulsion module, a second type was considered with a pump-fed FLOX-methane propulsion system. Differences in the flight vehicle design, such as thin-wall tanks vs containers capable of being evacuated, probably have more impact on prelaunch operations than the differences between the propellant properties. FLOX and methane do not create any new problems compared with OF_2 and B_2H_6. Some of the significant differences are noted below.

8.1 STORAGE

Methane is transferred and stored as a liquid in foam-insulated or vacuum-jacketed containers. For short term simplicity, boiloff may be vented or burned. For long term efficiency, boiloff can be burned in an engine to power a refrigeration system compressor. Insulated tanker trucks are commercially available for delivery.

Reference 33 notes that FLOX mixed at the pad is a serious drawback. Facilities are proposed for separate storage of LF_2 and LO_2 plus a vacuum-jacketed, LN_2-cooled FLOX tank for creating the mixture with composition sensing and control systems. Due to its lower boiling point, the fluorine tends to boil off at a higher rate than the oxygen. This differential boiloff could cause shifts in mixture ratio with time, such that the desired 82.5 percent F_2 in the FLOX misture for maximum spacecraft performance could not be assured. Even if the FLOX storage container is subcooled, with no boiloff, there would be uncertainty on what evolved from line and propulsion module chilldown.

Convair does not recommend three separate storage containers for LO_2, LF_2 and FLOX, but a single FLOX dewar. Differential boiloff during storage should be avoided by subcooling to LN_2 temperature. The mixture will have to be checked periodically. An allied trailer, discussed in Section 5, can be used to store the FLOX, or a permanent dewar could be built at the site if more than 5,000 pounds are required or more than 70 psi for loading in the tower.

By the time a FLOX program becomes operational, 82.5 percent FLOX will probably be commercially available. Even so, make up systems to adjust the mixture will be required. K-bottles of gaseous oxygen and fluorine can be used to bubble in vapor to mix and condense. Or LO_2 and LF_2 can be transported in with standard trailers. LN_2 jackets on the system will preclude boiloff.

8.2 THERMAL CONTROL

Thermal control of airborne tank propellants in a ground-hold condition, without boil-off, can be most easily and economically accomplished by single-pass refrigeration with low-cost cryogens, if they are available in the proper temperature ranges. If the two propellants are to be stored at the same temperature, then the refrigeration systems and thermal control can be even further simplified by use of a single airborne refrigerant and system, as has been discussed in thermal control of OF_2/B_2H_6 at 220°R.

If FLOX and methane, however, are to be stored in an airborne propellant module at temperature ranges of 140 to 180°R and 180 to 230°R respectively (by ground rule), then thermal control by single-pass refrigeration can only be reasonably accomplished by one of the following three methods:

1. Using two refrigerants and separate systems.
2. Using a single refrigerant, two-phase, first cooling the FLOX, then passing to refrigeration of the methane at a higher temperature.
3. Using a single refrigerant, at precisely 180°R.

All three methods are feasible, but not particularly desirable. The dual refrigerant system is more complex in both ground and airborne systems; the two-phase system is more difficult to control; and the single refrigerant system at 180°R is inflexible.

If the propellant storage temperature ranges can be overlapped, however, the thermal control problem for FLOX/methane becomes simple. Liquid nitrogen may be used as a single refrigerant in a single airborne system, boiling off through a ground storage tank at a 40 to 98 psig backpressure. The system is low-pressure, extremely low in operating cost, simple and inexpensive to install, reliable, and safe. The control system consists only of the storage tank backpressure relief system to maintain the 40 to 98 psig on the LN_2. The pressure range corresponds to a temperature range of 163° to 180°R. The range provides a sensitive control modulus of less than one degree ΔT per three psi control ΔP, maintains methane in its liquid range, and limits the FLOX tank vapor pressure to less than 50 psig (82.5% FLOX mixture).

Figure 8-1 shows the ground-rule thermal control ranges for FLOX and methane, and the suggested overlap to permit single-pass LN_2 thermal control of these propellants. The common-temperature control range for OF_2/B_2H_6 is also shown.

Thermal control of FLOX and methane in two different temperature ranges is more involved than the common-temperature control of OF_2/B_2H_6, but is not an insurmountable problem nor even difficult. GSE is essentially the same as for OF_2/B_2H_6 but

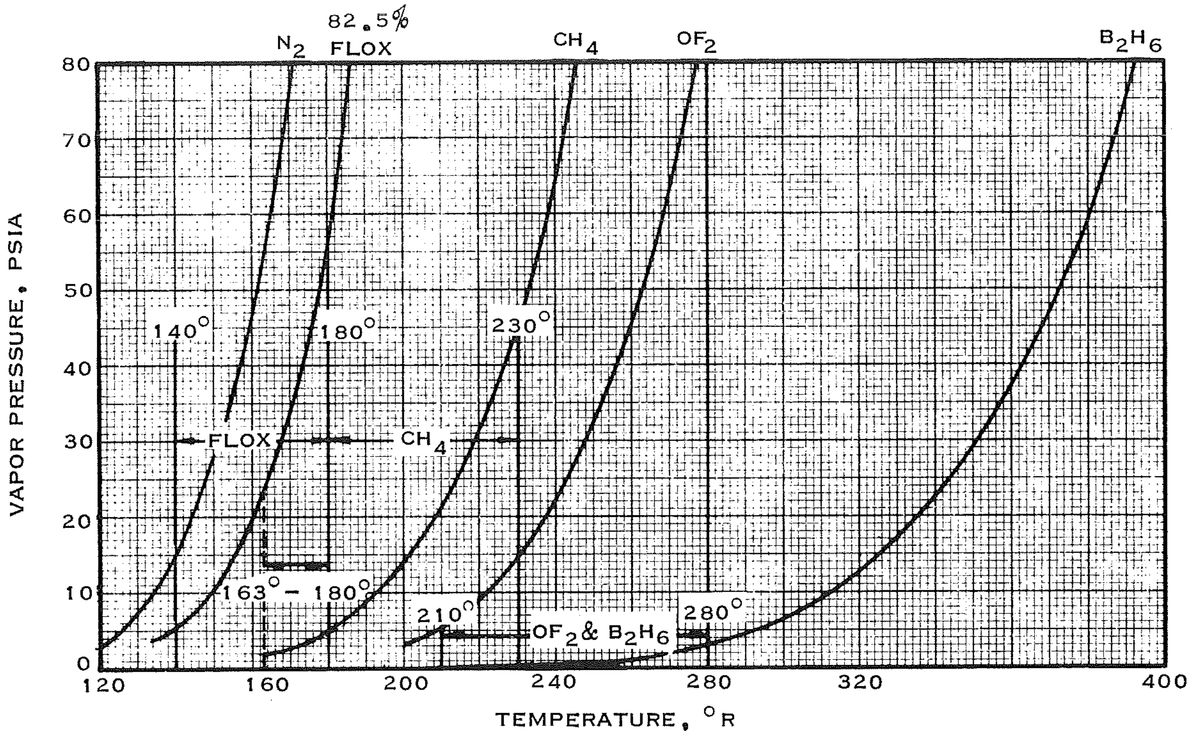


Figure 8-1. Propellant Vapor Pressures and Thermal Control Ranges

more complicated to control and probably therefore somewhat less reliable. If the ground-rule temperature ranges are not critical, then it is recommended that the methane lower limit be changed from 180°R to 163°R, permitting consideration of the simple single-pass LN_2 thermal control system just discussed.

8.3 LOADING

Major differences to be considered in propulsion module loading with FLOX/methane versus OF_2/B_2H_6 include:

Temperature characteristics.

Vapor pressures.

Toxicity, in relation to vent/no vent requirements.

Mixture (FLOX) versus monomolecular oxidizer effects.

Vehicle tank vacuum capability of high pressure (pressure-fed) versus low pressure (pump-fed) propulsion systems.

8.3.1 TEMPERATURE CHARACTERISTICS. With respect to propellant loading systems, those propellants which are close to the liquid nitrogen temperature range (Figure 8-1), are more adaptable to simple, inexpensive temperature control for no-vent transfer than are the less cryogenic propellants.

Oxygen, oxygen difluoride, fluorine and FLOX mixtures, for example, can be transferred in LN_2-jacketed lines, sub-cooled with no boiloff. The liquid nitrogen can be pumped near atmospheric pressure and re-circulated, removing nitrogen boiloff vapor in a separator vented to atmosphere.

Methane can be transferred in the same way, subcooled with no venting (if desired), if the nitrogen separator is maintained above 50 psig with back-pressure relief valves to atmosphere, to keep the methane above its 163°R freezing point.

Diborane, however, has a freezing point of 195°R, corresponding to a liquid nitrogen saturation pressure of 165 psig. The re-circulating nitrogen system is still workable, but cryogenic ground systems at this pressure are not particularly desirable. Other closed loop refrigerants and systems may be used, or the diborane may be transferred as a vapor as discussed previously, with due consideration given to decomposition effects.

FLOX and methane, then, can be regarded as somewhat more compatible with no-vent transfer systems than are OF_2/B_2H_6, with respect to system simplicity and cost.

8.3.2 VAPOR PRESSURES. Propellant vapor pressures (Figures 8-1 and B-2 through B-7) are closely related to methods of airborne propellant thermal control, Section 4, and to storage systems, Section 3, but do not directly affect subcooled no-vent transfer operations; temperature is the controlling factor. Vapor pressure does have an effect, however, on drain operations. OF_2 and B_2H_6 must be raised in airborne tank temperature above the desired control temperature of 220°R, to 230°R and 324°R, respectively, to attain vapor pressure drain to a storage dewar venting through a vapor disposal unit to atmosphere. Oxidizer is drained first; the temperature is then raised to allow B_2H_6 drain.

In a FLOX/methane system at a control temperature of 180°R, or 163° to 180°R, FLOX will drain under a positive gage vapor pressure without changing the thermal control temperature. The TCU must then be raised above 200°R to attain CH_4 drain.

The principle involved is the same for both propellant combinations; only the refrigerant temperatures corresponding to atmospheric saturation pressures are different.

8.3.3 TOXICITY. Whereas both OF_2 and B_2H_6 are toxic, requiring a no-vent transfer system, only FLOX requires a no-vent capability with the FLOX/methane combination. Methane may be vented to atmosphere from an elevated stack, eliminating the transfer system requirement for no-vent, and for extreme purge requirements.

8.3.4 FLOX MIXTURE EFFECTS. Use of FLOX as an oxidizer introduces a new factor which must be considered in design of a transfer system. Any stored mixture of fluorine and oxygen reaches a saturated equilibrium condition with its own vapor, with the vapor component ratio of F_2/O_2 higher in fluorine content than the liquid component ratio of LF_2/LO_2 (Figure B-9). This effect is completely irrelevant if the storage tank/transfer system/airborne tank system is held subcooled without venting, as has been done with the OF_2 transfer systems discussed earlier. If a transfer system is used which allows boiloff, however, particularly from the airborne tank when loaded, then the fluorine-rich boiloff gas continually lowers the fluorine content of the liquid FLOX mixture, affecting I_{sp}. Even with a closed loop system, condensation of boiloff gas introduces fluorine-rich condensate return mixing problems. Subcooling of both the transfer system and airborne tanks is therefore recommended for FLOX mixtures.

8.3.5 AIRBORNE TANK VACUUM CAPABILITY. The loading systems, suggested for OF_2 and B_2H_6, were based on high pressure airborne tanks capable of pulling a hard vacuum on the system, eliminating all non-condensable gases, and permitting loading without ullage gas venting. If the FLOX/methane propellant combination is to be used with a pump-fed propulsion system, then presumably the airborne tanks are low-pressure, lightweight, and may or may not be capable of 15 psi negative pressure. If they are designed for internal vacuum, then no problem exists. If not, then the systems as described for OF_2/B_2H_6 are inadequate for FLOX/CH_4.

If the FLOX/CH_4 tanks are not designed for inside vacuum, then the tanks must be vented to provide escape of ullage gas, and the ullage gas must be vented through a closed system to a vapor disposal unit.

As airborne tank capacity is increased, pressure fed propulsion systems lose their advantage to low pressure, lightweight tank configurations with pump-fed propulsion systems. Of necessity, large, lightweight propellant tanks will require loading at the launch complex with a vented transfer system.

8.4 FLOX/METHANE VS. OF_2/B_2H_6

Disregarding all aspects of propulsion module tank size, pressurization characteristics and mission performance, and considering only the effect of propellant combination on prelaunch systems and operations, the essential differences between FLOX/methane and OF_2/B_2H_6, summarized in Figure 8-2, can be compared as follows:

OF_2 Negative Aspects — Oxygen difluoride is an order of magnitude more restrictive in permissable exposure than is FLOX (at present), is highly reactive, and requires a no-vent loading system.

Positive — Can be easily transferred in a subcooled condition without boiloff, and held, with an atmospheric LN_2 jacketing system.

OF_2	B_2H_6		FLOX	METHANE
VERY HIGH	HIGH	TOXICITY	HIGH	NONE

PERSONNEL HAZARD REQUIRING SAFETY GEAR AND DETECTION EQUIPMENT. REQUIRES: NO-VENT STORAGE, TRANSFER, AND GROUND-HOLD SYSTEMS; SPECIAL STORAGE AREA AND DISPOSAL PROVISIONS. HANDLING OPERATIONS ARE WEATHER-RESTRICTED.

HYPERGOLIC	PYROPHORIC	REACTIVITY	HYPERGOLIC	FLAMMABLE

FIRE AND EXPLOSION HAZARD TO PERSONNEL AND EQUIPMENT. REQUIRES CRITICAL SYSTEM CLEANLINESS, PURGE, PASSIVATION AND MATERIAL COMPATIBILITY. REDUCES PROBABILITY OF MISSION SUCCESS.

NONE	ABOVE -100°F	DECOMPOSITION	NONE	NONE

CAN CONTAMINATE PROPELLANTS. REQUIRES SYSTEM DESIGN TO MAINTAIN LOW TEMPERATURE.

MONO	MONO	CONSTITUENTS	MIXTURE	MONO

MIXTURES REQUIRE COMPOSITION MEASURING EQUIPMENT AND SYSTEM DESIGN TO HOLD MIXTURE SUBCOOLED TO PREVENT PREFERENTIAL BOILOFF AND COMPOSITION CHANGE.

89°F	195°F	FREEZING POINT	98°R	163°R

LOWER THAN 140°R PERMITS USE OF ATMOSPHERIC LN_2 FOR SUBCOOLING.

Figure 8-2. Propellant Comparison

B_2H_6 — Negative — Diborane is pyrophoric, toxic, requires a no-vent loading system, is subject to decomposition (Figure B-8), and requires a liquid nitrogen pressure greater than 165 psig in the jacketing system (or a dual refrigerant system) to maintain it above its freezing point in storage and transfer.

Positive — Falls in the low-pressure Freon 14 (non-toxic, inert) refrigerant range, at the desired control range of 210 to 280°R.

FLOX — Negative — FLOX is a mixture, and therefore requires mixing and composition measuring equipment not needed for the other propellants. If allowed to boiloff, the composition changes (Subsection 8.2.4). FLOX is highly reactive, toxic, and requires a no-vent transfer system.

Positive — Can be easily transferred in a subcooled condition without boiloff, and held, with an atmospheric LN_2 jacketing system, without significant change in composition.

Methane Negative — Requires a pressurized (> 40 psig) LN_2 jacketing system to maintain it above its freezing point during storage and transfer.

Positive — Non-toxic, nonpyrophoric, not subject to decomposition, and can be freely vented.

In summary, FLOX/methane is less hazardous than OF_2/B_2H_6 from a standpoint of fire, safety, and reaction, requires less in the way of no-vent transfer systems, and can be thermally controlled with lower-pressure (near atmospheric) LN_2. These factors are a matter of degree, however, and can be accommodated by proper design, reflecting only the degree of system complexity and operational procedures.

Basic disadvantages of individual propellants, such as diborane decomposition and FLOX differential boiloff, are not serious and can be circumvented by proper design; i.e., maintain B_2H_6 below -100°F, and maintain FLOX subcooled at all times.

Both OF_2/B_2H_6 and FLOX/methane propellant combinations can be loaded aboard a space storables propulsion module and held without venting, with essentially the same type GSE. Again, complexity of the no-vent transfer systems and of the ground-hold system will be a matter of degree.

9

EVALUATION OF OPERATING PLANS

The many facets of prelaunch operations with a space storable propulsion module have been discussed. In this section the various elements are combined into operating systems and many possible operating plans are evaluated. The two basic propulsion module propellant loading modes are compared:

1. Propellant loading prior to encapsulation.
2. Propellant loading on the launch pad after encapsulation.

First it is necessary to judge what emergency action is best in case of various operating problems so that the overall systems can include safeguards like an emergency drain system, if necessary. Then a rating is made of several operating modes: three approaches to propellant loading at the ESF and four possible ways of tanking at Complex 41. All seven methods appear to be feasible.

Many of the opinions and judgments reflect input from the operations people at the Cape who assisted in this study. Although there were many preferences in all areas, all parties involved at KSC and AFETR were strongly favorable to this consideration of prelaunch operations so early in the technology and propulsion module conceptual stage.

9.1 INCIDENT ANALYSIS AND EMERGENCY ACTION

In order to determine the necessity of various emergency systems and procedures, a comprehensive review of possible failure modes and incidents has been made, together with appropriate reactions within KSC/ETR operating procedures. Thoughtful review of these findings indicates, for example, whether an emergency drain system is really useful, or whether its use would only compound the problem. Recommendations are based on the following philosophy:

> Minimum propellant transfer activity for minimum risk: when there is no problem with the propellant system, leave it alone.

Section 2.6 discussed meteorological restrictions based on the worst toxic hazard: rapid cold release of the entire OF_2 load. It was estimated that passivation and tanking would be restricted to favorable meteorological conditions with road blocks one mile around the ESF or two miles around Complex 41. Limited access directly to the spacecraft is assumed at other times. What emergency action should be initiated when other troubles occur such as indication of a small leak?

In Table 9-1, malfunctions and incidents are listed in order of increasing severity. The first few require routine preventive action whereas the lower, more serious problems involve emergency corrective steps. It is routine procedure to demate and remove a faulty spacecraft and replace it with a ready spare. It is normal to remove both payload and launch vehicle and store them while a hurricane passes the Cape. Less than eight hours is normally required to demate the spacecraft, lower out of tower, and return to ESF. Section 7.11 discusses the demating steps. Existing types of spacecraft have been handled "wet" and we recommend that procedures be set up to allow a space storable propulsion module to be demated and removed while loaded.

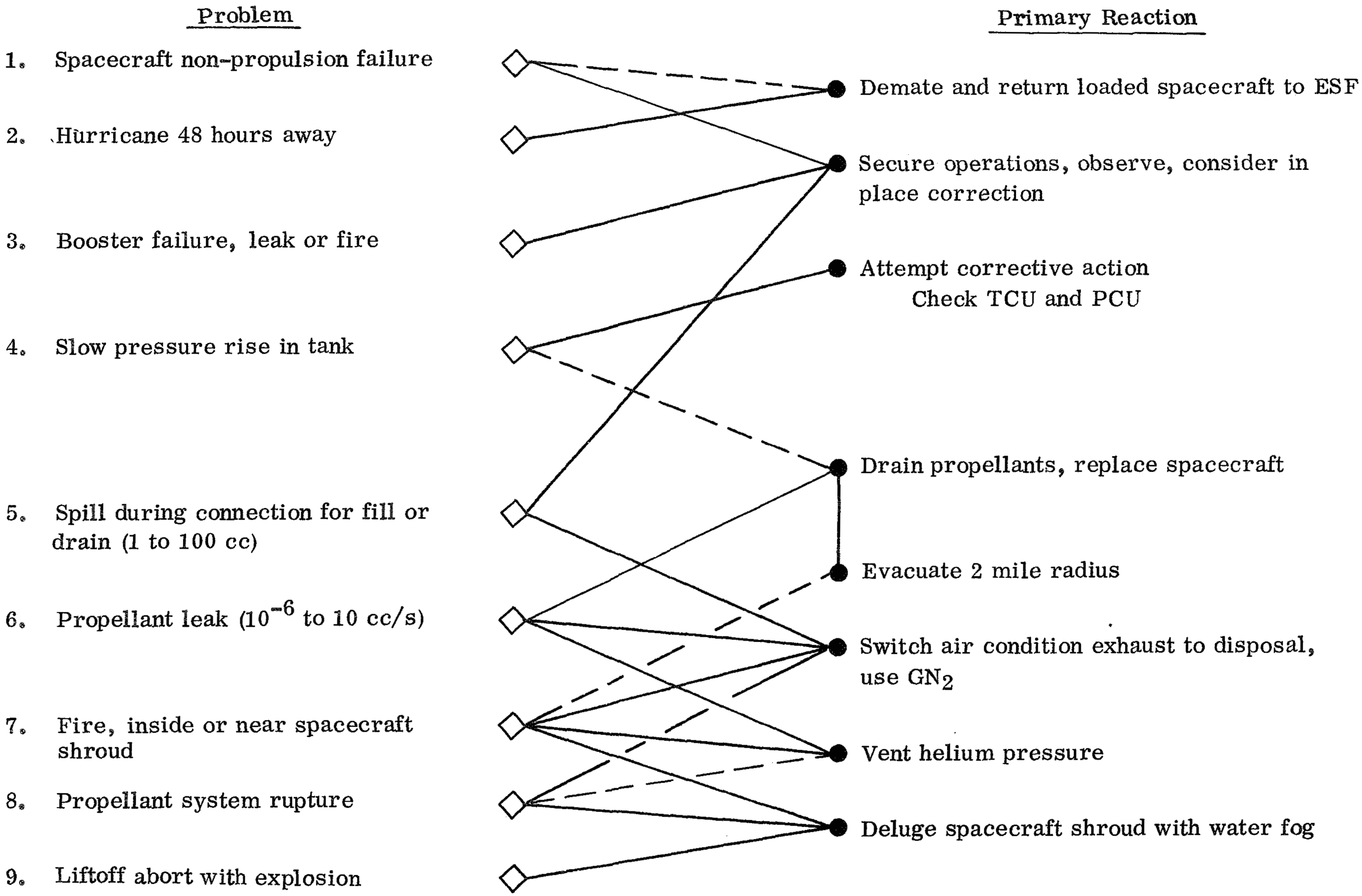
A variety of booster problems can jeopardize the spacecraft without requiring emergency spacecraft procedures. A leak or local fire on the Titan or Centaur can probably be handled without affecting the spacecraft. Probably there would not be time to drain the space storable propellants, and in fact this could increase the hazard by wetting umbilical lines. In case of enveloping flames from below, applying water fog would cool the shroud. It is probable that the entire vehicle would be replaced after a serious booster failure.

A slow pressure rise in the spacecraft propellant tank(s) would most likely be due to thermal control or pressurization system failures. A reaction in the OF_2 system would either produce a sudden jump in pressure or a burn-through. With SCAPE suits readily available, technicians should first try to check and correct any GSE problems. The TCU and PCU may be within 20 feet of the vehicle. At 220°R, B_2H_6 has essentially zero vapor pressure while OF_2 is about 10 psia, allowing time to replace the entire ground thermal control unit, if necessary, since it takes about 24 hours for the propellant vapor pressure to rise 150 psi. If these efforts were ineffective, there is still time to drain propellants and remove the spacecraft. For personnel safety, corrective action would be closely monitored with workmen in pairs. The spacecraft design should allow a way to vent helium pressure in case of a pressurization system malfunction through a ground pressure control unit (PCU) connected through a launch umbilical to the propulsion module. Its basic function would be to bring the tanks up to 100 to 240 psi before launch, but the PCU would also have emergency uses. If a pressure limit is exceeded, the area should be evacuated while corrective action is being attempted.

The above problems are typical of the group which can usually be handled the same as with any spacecraft with no unusual requirements due to space storable propellants. Due to the hazardous situation, no corrective action would be attempted without careful preparation. Below are discussed a more serious group which necessitates special precautions such as evacuating a two mile area in case of large propellant releases.

A finite spill might occur after tanking or draining when connecting or disconnecting lines. Propellant loading should be done by remote operation, but the fill and drain line would be manually disconnected. Proper system design will provide shutoff valves in the GSE and on the spacecraft, on each side of the disconnect. Thorough

Table 9-1. Reaction to a Malfunction or Incident



purging, evacuating, and sampling will be required before manual disconnect. Nevertheless precautions must be taken against accidents: connections should be made only when the workers involved are wearing SCAPE suits and those not involved are cleared from the area. Beneath the connection points must be a compatible floor or stainless catch basin. If a spill occurs, workmen must immediately leave the area, the air conditioning may be switched from atmospheric air to GN_2, and its exhaust may be switched to the disposal/neutralizer system. Probably the spill will evaporate in a few seconds and be disposed of through the air conditioning system without permanent trouble. Water fog should not be used on a small spill because it will create a reaction where one might have been avoided. It may be possible to automatically blow in a neutralizer, like powdered lime on an OF_2 spill. Draining obviously should not be initiated. Explosion-proof electrical equipment in the area is essential. A spill is unlikely to occur, but if it does, the consequences should be minor with proper planning, training, and equipment.

When leakage is detected by the hazard sensing system, immediate emergency procedures should be initiated. Even though the leak indication is very small, it is serious. With reactive propellants, even a small leak may initiate a fire or explosion. A leak of 1.5 cubic centimeters per minute, mixed in the shroud air conditioning exhaust raises the contamination to the threshold limit value of 0.05 ppm for OF_2. A tiny leak under the airborne tankage insulation system may accumulate a long time before it can be sensed in the shroud air conditioning exhaust, so any inflight leaks are unacceptable.

Any leakage indication, then, necessitates replacing the spacecraft. With such expensive spacecraft and important missions at stake, one should not take the chance that the leak will cure itself by icing. It is mandatory that propellants be drained and purged as soon as possible. A leaking spacecraft cannot be handled or transported.

Since the leakage problem may get worse, the area must immediately be evacuated for two miles, the air conditioning switched from air to GN_2 and from open discharge to disposal unit, and all workmen must wear SCAPE suits to attach drain lines, etc., as required. Naturally, it would be advantageous to know (by instrumentation or observation) which propellant is leaking. A leak is the basic reason for recommending an emergency drain system at Complex 41.

The motion, vibration, and relatively inconvenient arrangement during caravan from the ESF to Complex 41 probably increase the chance of a leak, pressure rise or even a reaction. Emergency action on the road is more difficult than in the ESF or Complex 41. Motions during launch ascent are more violent than in caravan; from a program success standpoint it is better to uncover problems in caravan than in flight. Moving a loaded spacecraft is undesirable from a safety viewpoint, but can be successfully done with carefully made plans to handle emergencies by using the VDU or available mobile dewars.

There is a final, very serious group of incidents which will most probably cause the loss of the spacecraft. In these cases, efforts should be concentrated on saving personnel and the site. A fire in the spacecraft from an electrical malfunction, an OF_2 reaction, or an appreciable propellant leak might lead to a violent fire or explosion. If a fire occurs, the reaction is likely to be so rapid that no attempt can be made to extinguish the flame.

After the fluorine-fed fire has subsided and the fluorine has been consumed, or has evaporated, efforts should be directed toward reducing secondary fires. Water fog should be applied on the burning spacecraft or shroud to cool adjacent items. Personnel must dive to safety, even into an escape chute or wire if available. There is no point in draining unless it is an obviously small, controllable fire. Any helium pressure in the propellant system should be vented.

Such major incidents can lead to a propellant tank rupture. Operator error during handling or testing can also puncture or overstress a tank. Again personnel must escape immediately, then water must be applied while pressure is vented. Such a rupture or an inflight abort would constitute an instantaneous release of all the propellants resulting in maximum toxicity hazard. When handling a loaded spacecraft, during pressurizing, and during launch countdown, exclusion of non-essential personnel beyond the two-mile limit is required. The blockhouse should have emergency breathing provisions. Hazard sensors should be located on the inlet to the blockhouse outside air supply to detect toxic gases from either the booster or spacecraft. Blockhouse inlet air would have to be blocked when the toxic level reach TLV.

A spill basin lined with limestone may be a useful concept around the ESF, but not once the spacecraft is erected on top of the booster at the launch complex. There, 135 feet above the ground, most of a propellant spill will evaporate, react, or burn before it hits the ground (probably the flamebucket), even from a complete tank rupture.

A major conclusion is drawn from this discussion of emergency action: an emergency drain of the spacecraft propellant tanks is definitely recommended for use when a leak has been detected. Emergency drain is considered for secondary action in case of booster failures, a slow pressure rise, a fire, and a propellant tank rupture. More frequently used is a propellant tank vent through the PCU.

This means that even for the operating plan where the propulsion module is loaded in the ESF, we still recommend an emergency drain system be available at Complex 41. This could result in duplicate propellant systems, for the emergency drain would have to be purged, passivated, and completely checked out even if never used. This recommendation then forces either spacecraft propellant systems launch disconnects or manual disconnects to be serviced through a shroud access door.

9.2 COMPARISON OF BASIC OPERATING PLANS

Should the propulsion module be loaded in the Explosive Safe Facility Propellant Lab (ESF-PL) as were the Surveyors and Mariners, encapsulated, and left untouched at the launch site? Or does the cryogenic, toxic, and reactive nature of the propellants dictate handling like the Centaur with tanking late in the launch countdown? The choice requires consideration of many parameters ranging from ground safety to the thoroughness of propulsion system functional checks. We do not feel propellant thermal control is a deciding factor. As discussed in Section 4, a simple mobile GSE unit can be integrated with the airborne system. We believe that safety and mission success considerations are keys to the choice. Table 9-2 shows which propulsion prelaunch operations would be done at the ESF and which at Complex 41 for seven different propellant loading schemes. The equipment required for these functions are schematicly shown in the next seven figures. The relative merits and problems are then discussed in order to arrive at a rating and selection.

Figure 9-1 schematically itemizes Propellant Module Loading Scheme No. 1, tanking at the ESF-PL, sealing up before encapsulation. No propellant or propulsion servicing is provided at Complex 41. This is the technique successfully used on all previous spacecraft including Surveyors and Mariners. It has the main advantage of simplicity: all propellant handling equipment and personnel are at one location.

Scheme No. 2, shown in Figure 9-2, is the same as Scheme No. 1 with the addition of manually connected emergency vent and/or drain provisions at Complex 41. This means duplication of some piping and GSE in order to be able to drain in case of a leak, and an access door in the vehicle shroud. The drain lines are envisioned as inexpensive one-inch-diameter pipes, foam insulated. This system may vapor lock temporarily to initially delay draining.

Scheme No. 3, Figure 9-3, is the most complex of the three approaches to tanking at the ESF. Emergency drain and vent are provided right up through launch, into LN_2 jacketed dewars located in the 12th level of the umbilical tower for rapid drain.

Figures 9-4, 9-5 and 9-6 show three variations of propellant loading at Complex 41. Prior to encapsulation, the propulsion module would have been leak tested at the ESF with LN_2 and helium. The actual tanking with B_2H_6 and OF_2 would occur at the launch complex. Scheme No. 4, Figure 9-4, uses the freight elevator in the mobile service tower (MST) to bring propellant supply carts up to the spacecraft. At first glance this would seem very simple, but the requirement for LN_2, vacuum, and helium purge teeing into the propellant lines complicates the system, even adding extra disconnects at the base of the MST. A new mobile OF_2 trailer would be required because a leased Allied trailer would not fit in the elevator.

Table 9-2. Propellant Loading Schemes

	1	2	3	4	5	6	7
At ESF — Propellant Lab							
Passivate, leak & LN_2 check OSE	X	X	X	*	*	*	*
Ambient & LN_2 leak & functional checks	X	X	X	X	X	X	X
OF_2 passivating, fill, pressurize to 100 psi	X	X	X	*	*	*	*
B_2H_6 fill & pressurize to 100 psi	X	X	X	*	*	*	*
Weigh	X	X	X				
Pressurize propellant tanks to 240 psi	X						
Hi pressurize helium charge to 2000 psi		X	X	*	*	*	*
to 4000 psi	X						
At Complex 41							
Passivate, leak & LN_2 check OSE		X	X	X	X	X	X
Ambient & LN_2 leak & functionals				X	X	X	X
OF_2 passivating, fill, pressurize to 100 psi				X	X	X	2
Pressurize to 240 psi		X	X	X	X	X	X
B_2H_6 fill & pressurize				X	X	X	2
Pressurize to 240 psi		X	X	X	X	X	X
Measure propellant load				X	X	X	X
Hi pressurize helium charge to 2000 psi					X	X	
to 4000 psi		X	X	X	X	X	X
Emergency drain capability		X	X		X	X	X
Disconnect @ T-8 hours		X			X	X	

*Recommended, but omitted for comparison.

2 = twice: tanking test and launch countdown.

MAIN FEATURES:

COMPLETE ALL PROPELLANT AND PRESSURIZATION WORK IN ESF

NOTE: THIS WAS STANDARD PRACTICE ON SURVEYOR, MARINER, ETC

ADVANTAGES:

HIGH MISSION SUCCESS

MIN. LAUNCH DISCONNECTS

MAX LEAK + FUNCTIONAL TESTS

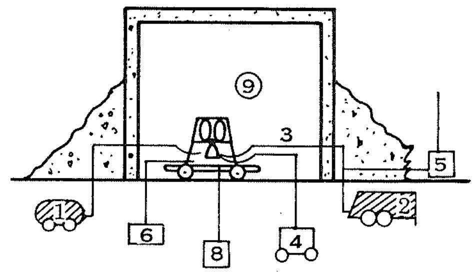
LOW COST

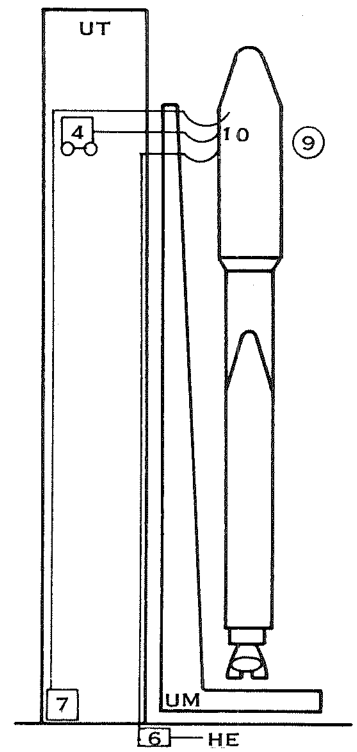
DRAWBACKS:

HIGHER RISK TO PERSONNEL. EXPOSES BOTH SITES

NO EMERGENCY DRAIN @ COMPLEX 41

MAX TIME AT FULL PRESSURE





GSE SYSTEM	ESF-PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER	MOBILE*		
2. OF_2 CONTAINER	ALLIED TRAILER		
3. FILL AND DRAIN SYSTEM	SHORT		
4. TCU	MOBILE	OPTIONAL	(MOVE FROM ESF)
5. VDU	1	OPTIONAL	
6. INSULATION PURGE	1	1	1
7. ECU		MOBILE	1
8. PCU	1		
9. HAZARD SENSORS	1	1	1
10. LAUNCH DISCONNECTS			3

*COULD USE FOUR 200-POUND CONTAINERS.

Figure 9-1. Propellant Module Loading Scheme No. 1, Tank and Seal up at ESF

MAIN FEATURES:

SAME AS NO. 1 PLUS

EMERGENCY DRAIN @41 TO TOWER BASE

REMOVED AT T–8 HOURS

ADVANTAGES:

HIGH MISSION SUCCESS

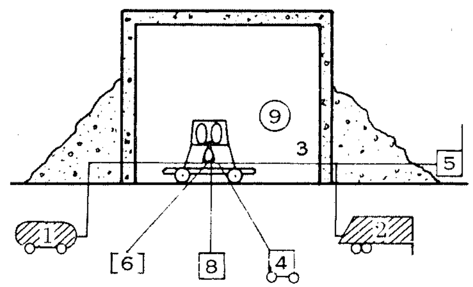
EMERGENCY DRAIN PROTECTS SITE + L.V.

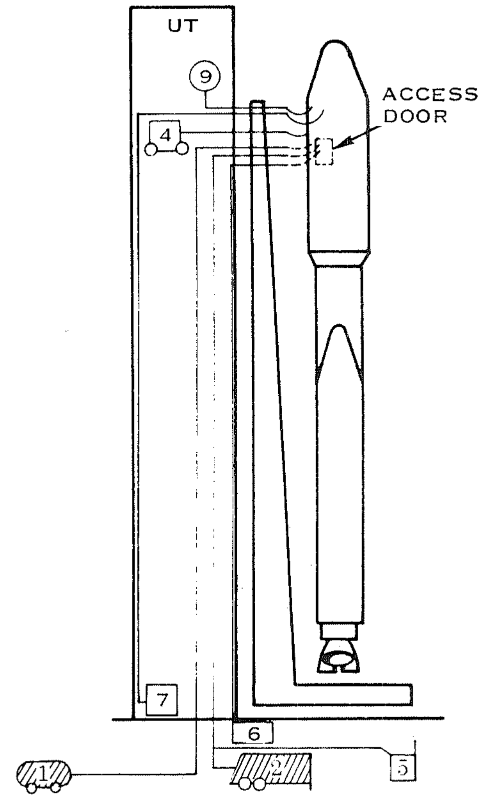
DRAIN AWAY FROM PROBLEM

DRAWBACKS:

MANUAL HOOKUP THRU ACCESS DOOR

EMERGENCY DRAIN MORE COMPLEX





GSE SYSTEM	ESF–PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER	1 MOBILE		(MOVE FROM ESF)
2. OF_2 CONTAINER	1 TRAILER		(MOVE FROM ESF)
3. FILL AND DRAIN SYSTEM	1 SHORT		1 LONG
4. TCU	1 MOBILE	OPTIONAL	1
5. VDU	1	OPTIONAL	1
6. INSULATION PURGE	1	1	1
7. ECU		MOBILE	1
8. PCU	1		1
9. HAZARD SENSORS	1	1	2
10. LAUNCH DISCONNECTS			4

Figure 9-2. Propellant Module Loading Scheme No. 2, Tank at ESF, Emergency Drain at Complex 41

MAIN FEATURES:

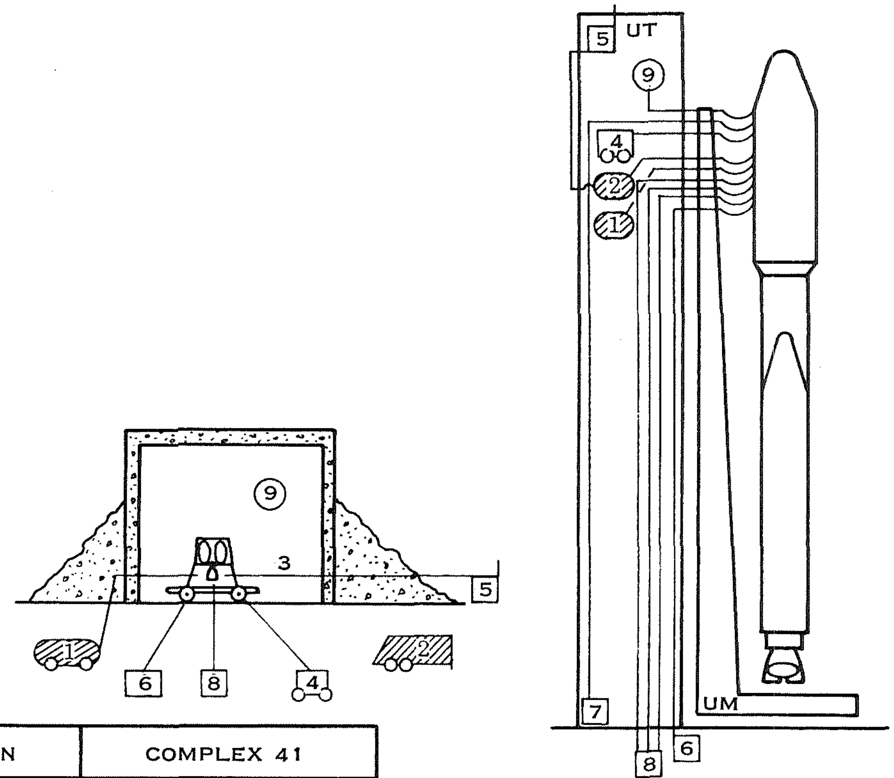
SAME AS NO. 2 EXCEPT DRAIN RECEIVERS IN UMBILICAL TOWER PLUS NINE DISCONNECTS

ADVANTAGES:

EMERGENCY DRAIN QUICKER
EMERGENCY DRAIN AVAILABLE UP TO LAUNCH

DRAWBACKS:

HIGHEST COST
MAXIMUM INFLIGHT DISCONNECTS
VERY CROWDED 12TH LEVEL OF UT
PROBLEM REMOVING DRAIN TANKS



GSE SYSTEM	ESF-PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER	1	AVAILABLE	1 CATCH
2. OF_2 CONTAINER	1 TRAILER	AVAILABLE	1 CATCH
3. FILL AND DRAIN SYSTEM	1 SHORT		1 SHORT
4. TCU	1 MOBILE	OPTIONAL	MOVE FROM ESF
5. VDU	1	OPTIONAL	1
6. INSULATION PURGE	1	1	1
7. ECU		MOBILE	1
8. PCU	1	OPTIONAL	1
9. HAZARD SENSORS	1	1	2
10. LAUNCH DISCONNECTS			9

Figure 9-3. Propellant Module Loading Scheme No. 3, Tank at ESF, Emergency Drain in Tower

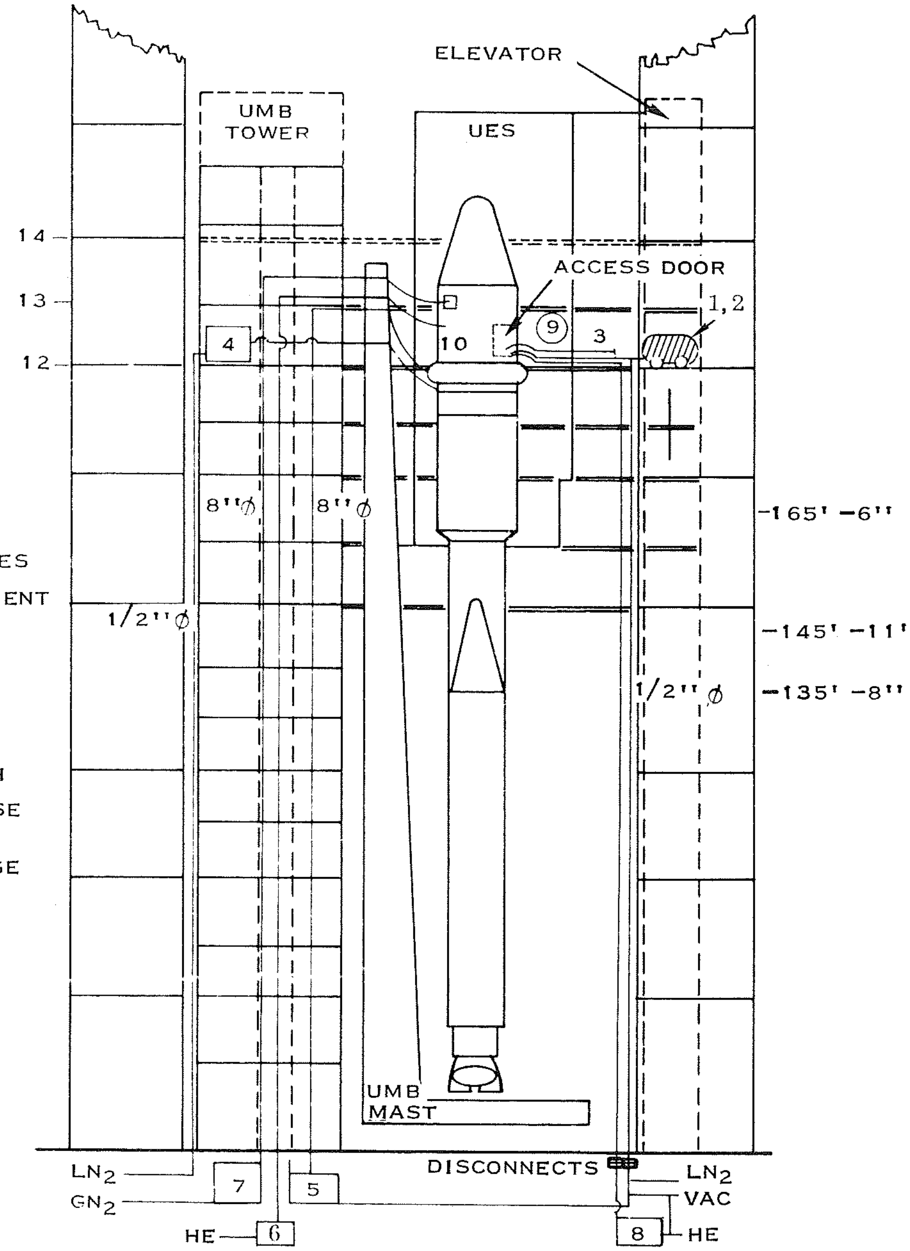
ADVANTAGES:

- SIMPLE AND LOW COST
- VERY SHORT PROPELLANT LINES
- MINIMUM PERMANENT EQUIPMENT ON SITE

DISADVANTAGES:

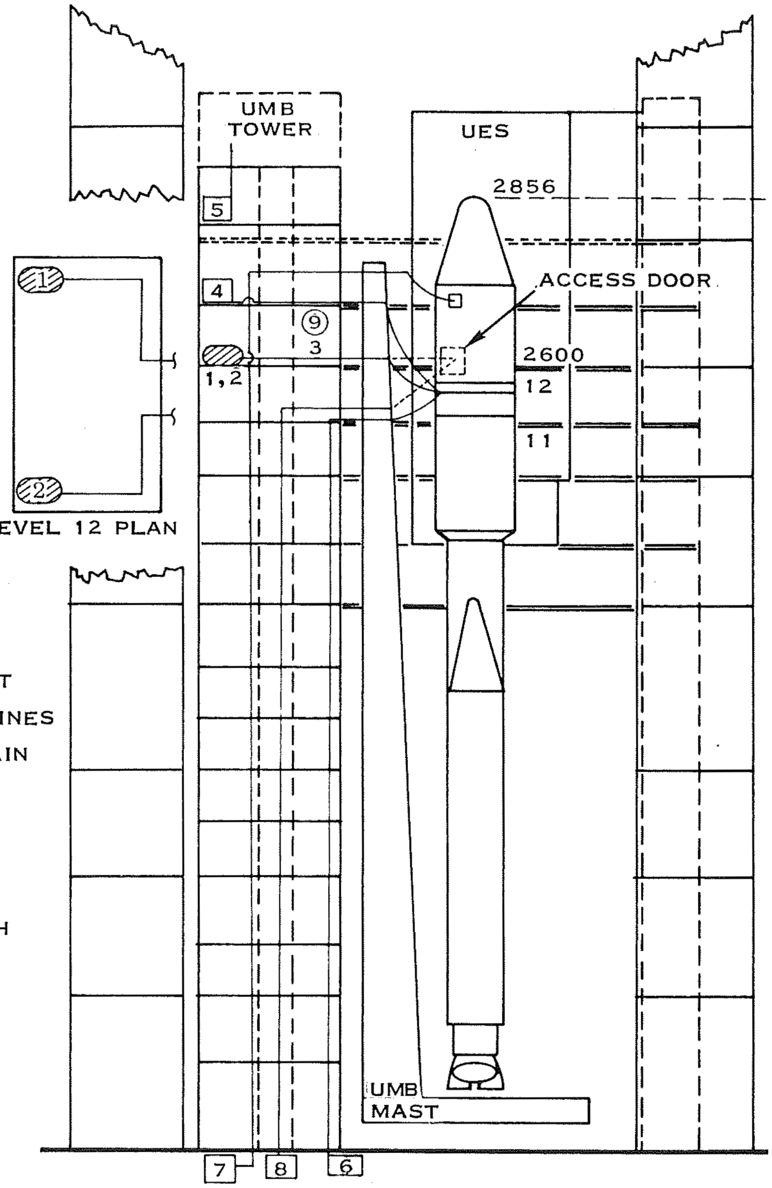
- NO EMERGENCY DRAIN
- CONTAMINATION CHANCE WITH DISCONNECTS IN UES AND BASE MST
- DOOR EXPOSES S/C TO DAMAGE

*COULD USE FOUR 200-POUND CONTAINERS.



GSE SYSTEM	ESF-PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER			1 MOBILE *
2. OF_2 CONTAINER			1 MOBILE
3. FILL AND DRAIN SYSTEM	1 SHORT (LN_2)		1 SHORT
4. TCU			1
5. VDU			1
6. INSULATION PURGE	1		1
7. ECU		MOBILE	1
8. PCU	TEST ONLY		1
9. HAZARD SENSORS.			1
10. LAUNCH DISCONNECTS			3

Figure 9-4. Propellant Module Loading Scheme No. 4, Load at Complex 41 from Mobile Dewars in MST



ADVANTAGES:

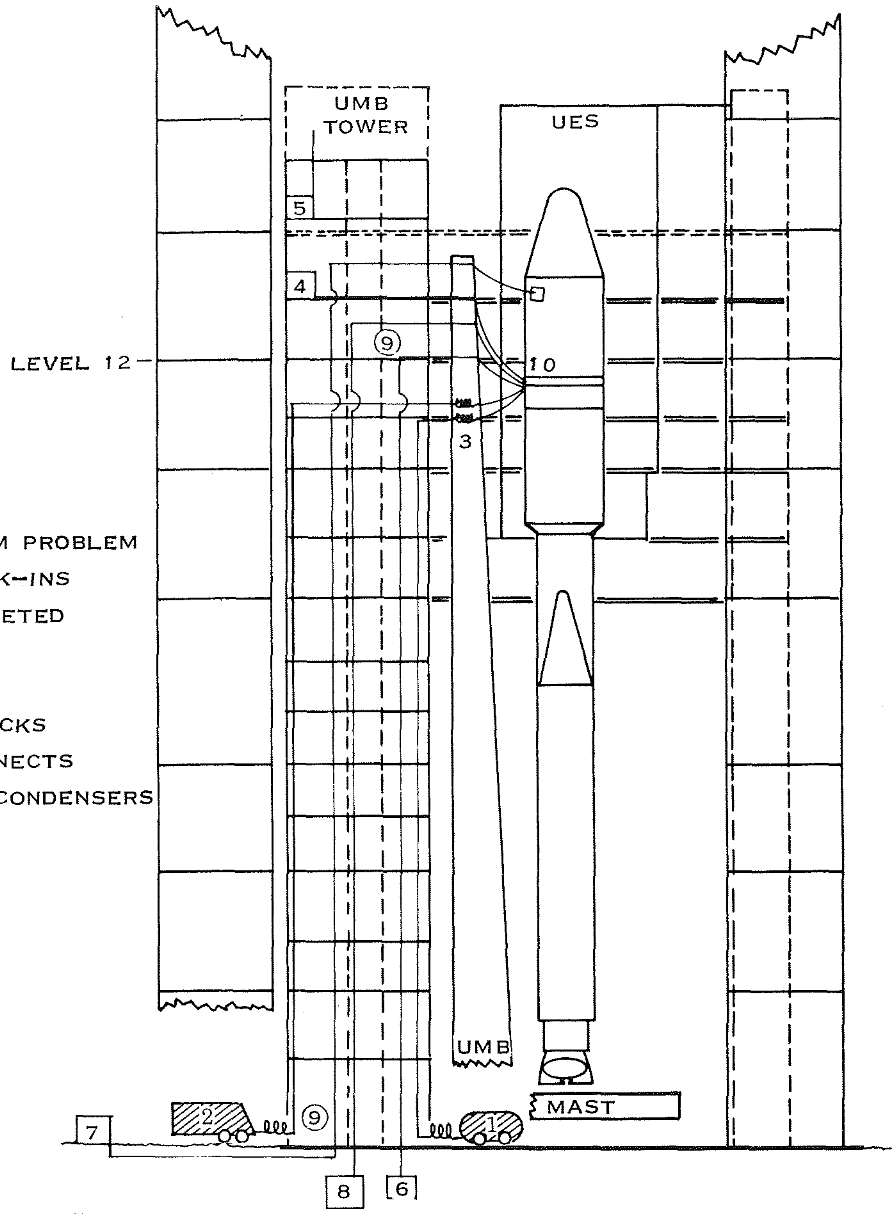
- SIMPLE AND LOW COST
- SHORT PROPELLANT LINES
- FAST EMERGENCY DRAIN

DISADVANTAGES:

- NEW OF_2 DEWAR
- DOOR EXPOSES S/C
- LIFTING DEWARS WITH CRANE
- ADDED INFLIGHT DISCONNECTS

GSE SYSTEM	ESF–PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER			1 MOBILE
2. OF_2 CONTAINER			1 MOBILE
3. FILL AND DRAIN SYSTEM	1 SHORT (LN_2 ONLY)		1 SHORT
4. TCU			1
5. VDU			1
6. INSULATION PURGE	1		1
7. ECU		MOBILE	1
8. PCU	TEST ONLY		1
9. HAZARD SENSORS			2
10. LAUNCH DISCONNECTS			5

Figure 9-5. Propellant Module Loading Scheme No. 5, Tank at Complex 41, Dewars in UT



ADVANTAGES:

- LOWEST COST
- HIGH SAFETY
  - DRAIN AWAY FROM PROBLEM
  - NO SYSTEM BREAK-INS
- DOOR IN SHROUD DELETED

DISADVANTAGES:

- "REMOTE" LEAK CHECKS
- MANY FLIGHT DISCONNECTS
- SLOW LOADING WITH CONDENSERS

GSE SYSTEM	ESF-PL	CARAVAN	COMPLEX 41
1. B_2H_6 CONTAINER	OPTIONAL		1 DEWAR-BEHIND BLAST WALL
2. OF_2 CONTAINER	OPTIONAL		1 ALLIED TRAILER
3. FILL AND DRAIN SYSTEM	1 SHORT (LN_2 ONLY)		1 LONG W. COND.
4. TCU	OPTIONAL		1
5. VDU	OPTIONAL		1
6. INSULATION PURGE	1		1
7. ECU		1 MOBILE	1
8. PCU	TEST ONLY		1
9. HAZARD SENSORS	OPTIONAL		2
10. LAUNCH DISCONNECTS			6

OPTION: LOAD LIQUID, BUT HIGH PRESSURE OF_2 DEWAR REQUIRED; LN_2 COAXIAL LINES WOULD SPEED DRAIN.

Figure 9-6. Propellant Module Loading Scheme No. 6, Load Vapor from UT Base

Scheme No. 5, Figure 9-5, is a variation on Scheme No. 4 with propellant supply dewars lifted by crane temporarily into the fixed umbilical tower (UT). This approach provides emergency drain. Level 12 of the umbilical tower becomes crowded and would require reinforce flooring.

Scheme No. 6, Figure 9-6, proposes to actually transfer vapor rather than liquid and recondense it in the propulsion module tanks. Vapor transfer is attractive for several reasons: the existing Allied OF_2 tailer rated at 70 psi will suffice (more than 100 psi would be required to lift liquid) and the error in weighing the dewar due to propellant in the lines would be very small. The general arrangement of piping and dewars is the same as for emergency drain in Schemes 2 and 3.

Propellant Loading Scheme No. 7, Figure 9-7, reflects the technique currently used on Centaur-tanking during the terminal countdown. Long, coaxial LN_2 jacketed lines from permanent site dewars through launch disconnects mean complicated plumbing. This technique becomes increasingly attractive as the size and danger of the propellant load grows.

Even when the final loading is done at Complex 41, we recommend complete checkout tests in the ESF, including passivation, loading, pressurizing, and draining. This thorough checkout minimizes the chance of losing the expensive spacecraft from a reaction during initial tanking.

The launch disconnects assumed for each loading scheme are shown in Table 9-3. Schemes 1 and 4 have minimum disconnects because no emergency drain is provided. Schemes 3 and 7 have maximum disconnects including emergency dump and vent through launch. Schemes 2, 5, and 6 utilize an access door so the emergency service lines are manually removed before launch.

Ten basic items of GSE are required in any case, such as B_2H_6 storage containers, a propellant thermal control unit (TCU), and three or more launch disconnects. The seven different arrangements of these items are compared from three viewpoints. The most important viewpoint is mission success, where a main question is: how much do the inflight disconnects for propellant fill, helium charge, etc., degrade spacecraft reliability by adding potential leaks? A 24-inch access door in the standard Centaur shroud improves the chances of mission success by allowing inspection and manual rather than inflight disconnects. Procedures and design must prevent "tweaking" or inadvertent operation of the spacecraft.

We believe that all seven approaches can be made safe. Tanking at the ESF would be weather restricted as discussed in Section 2.6, which can cause delays until wind direction and temperature gradients are acceptable. The least risk of personnel injury is achieved by tanking at Complex 41 late in the launch countdown, when everyone is evacuated for a distance of about four miles. On the other hand, the highest risk of loss of payload, launch vehicle, and site occur during passivation and tanking at Complex 41 without prior loading at the ESF.

ADVANTAGES:

SAFEST

PROPELLANT IN S/C ONLY DURING TANKING TEST AND COUNTDOWN

PERMANENT, VACUUM JACKETED SYSTEM

FAST DRAIN AWAY FROM PAD

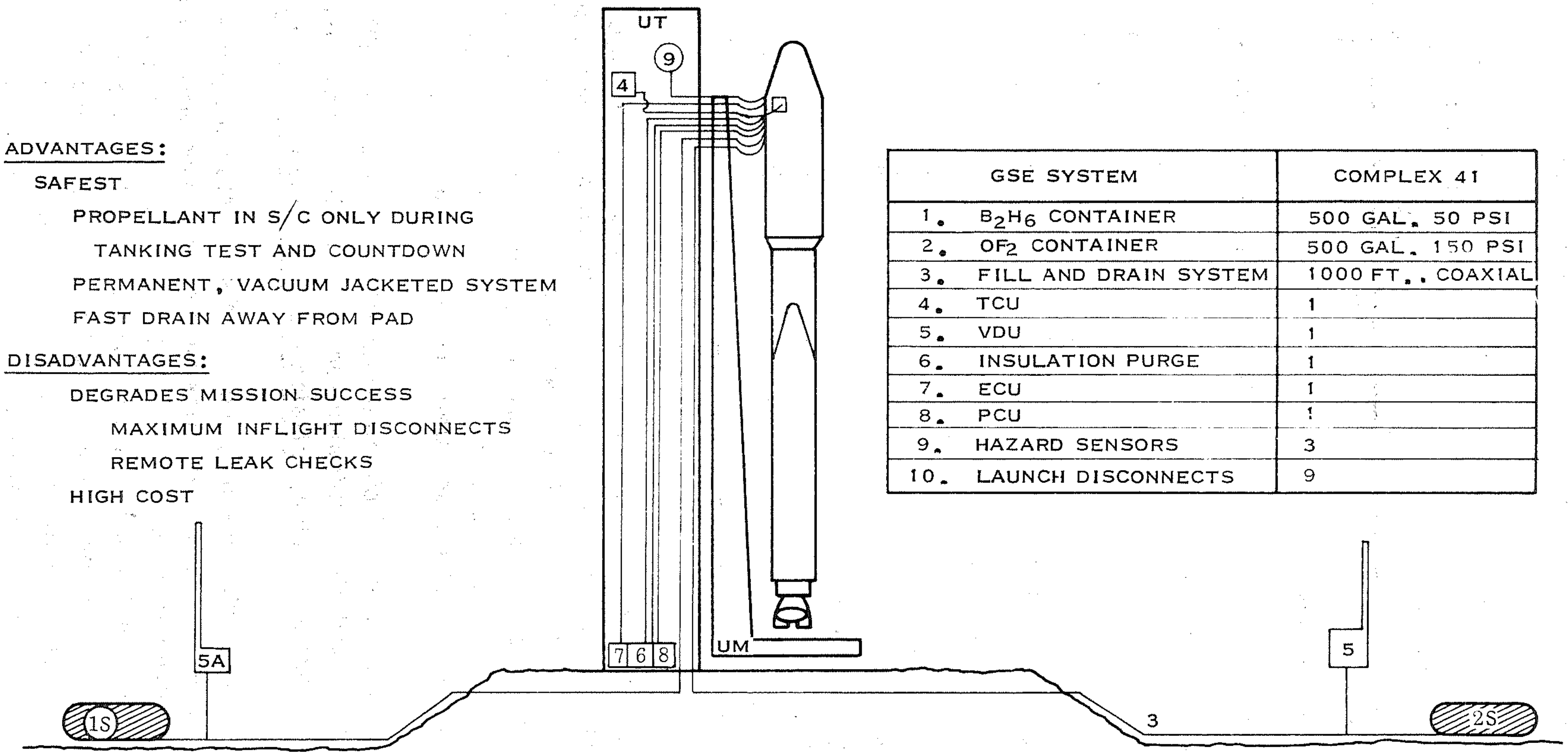
DISADVANTAGES:

DEGRADES MISSION SUCCESS

MAXIMUM INFLIGHT DISCONNECTS

REMOTE LEAK CHECKS

HIGH COST



GSE SYSTEM	COMPLEX 41
1. B_2H_6 CONTAINER	500 GAL., 50 PSI
2. OF_2 CONTAINER	500 GAL., 150 PSI
3. FILL AND DRAIN SYSTEM	1000 FT., COAXIAL
4. TCU	1
5. VDU	1
6. INSULATION PURGE	1
7. ECU	1
8. PCU	1
9. HAZARD SENSORS	3
10. LAUNCH DISCONNECTS	9

NOTE: SINCE COMPLEX 41 WILL LAUNCH MANY TYPES OF S/C, PERMANENT B_2H_6/OF_2 SYSTEMS ARE IN THE WAY.

THIS IS THE TYPE SYSTEM PROBABLY REQUIRED FOR LARGER PROPULSION MODULES.

COMPLETE PROPELLANT AND PRESSURE CHECKS RECOMMENDED FIRST IN ESF.

Figure 9-7. Propellant Module Loading Scheme No. 7, Complex 41 Loading, Permanent Installation

Table 9-3. Loading Scheme Launch Disconnects

Disconnect Assumed	Loading Scheme						
	1	2	3	4	5	6	7
a. TCU (2 mandatory)	2	2	2	2	2	2	2
b. Insulation Purge (mandatory)	1	1	1	1	1	1	1
c. ECU (mandatory)	Not	to spacecraft; through shroud only.					
d. Hazard Sensing (inside shroud)		1	1			1	1
e. B_2H_6 Fill and Drain			1		1	1	1
f. OF_2 Fill and Drain			1		1	1	1
g. B_2H_6 Pressurization and Vent			1				1
h. OF_2 Pressurization and Vent			1				1
i. Helium Charge and Vent			1				1
Possible Additions: Propellant Line Purges; Pneumatic Controls to e,f,g, or h							
TOTAL	3	4	9	3	5	6	9

Total cost of design, procurement, installation, and checkout of the propellant loading system is of the order of one million dollars. Some estimates are based on actual 1963 Centaur/Surveyor procurement. No attempt has been made to extrapolate to 1975 dollars. At best the cost comparison is intended to show that no system is very simple; all should be within 40 percent of each other. Cost is considered less important in selecting a propellant loading mode than safety and mission success.

9.2.1 MISSION SUCCESS. What effects do prelaunch operations and GSE systems and procedures have on the probability of mission success? As long as the costs are reasonable and the safety risks acceptable, mission success is the key parameter.

Flight vehicle design constraints caused by the use of space storable propellants are discussed in Section 7. As the spacecraft mission and the ground operations become better defined, clearer evaluation can be made. It appears from very preliminary information available today that propulsion functional checkout, leak test, and reaction checks can best be accomplished by loading in the ESF long before launch, where the system is accessible. From the viewpoint of achieving mission success, but not necessarily cost, it would be better to discover a slow leak or reaction on the ground and replace the spacecraft rather than lose it in flight.

Propellant loading can cause malfunctions in the spacecraft; for example, a valve may react or freeze. It is recommended that everything possible be re-checked after tanking. It may be impossible to operate the main propellant valves, pyrotechnic actuators, and other designs. Using LN_2 as a propellant thermal simulant, some checks may be safely accomplished which could not be done with the real propellants on board. With a TCU that can freeze the propellants, other realistic checks may be safe. It would further be desirable to let considerable time elapse after tanking until checkouts in case problems develop slowly. What does a check one or two days after loading mean on a 550-day mission to Jupiter?

For example, the pressurization system should be checked some time after tanking. A good procedure would be to pressurize to a low level — say 100 psi — after tanking, then to launch pressure — about 240 psi — a week later, using the actual flight helium supply and control system. This would require having a PCU hooked into the spacecraft in case of malfunction and/or to replenish helium. For this kind of testing, where conceivably a leak or reaction might result, the ESF-PL is much better suited than is the launch pad.

It is conceivable that using large shroud access doors at Complex 41, special temporary hookups might enhance checkout, although these special connections for test may degrade spacecraft performance. On Scheme No. 7, a tanking test a week or two before launch is intended as a cold checkout, although entirely remote.

Table 9-4 compares the chances of mission success for the seven propellant loading schemes. Assuming there are no catastrophes, tanking at the ESF gives better assurance of mission success:

1. Leaks can be double checked over a 30-day period both at ESF and at Complex 41. After no problems are uncovered in a week or two, the chance of any arising in flight are reduced. The dynamics of caravan transportation somewhat simulate launch conditions. The motion, vibration, and jerking in handling in the ESF and moving from the ESF to Complex 41 probably increase the chance of a leak, pressure rise or even a reaction. But from a program success standpoint it is better to uncover problems in caravan than in flight. The fact that the propellant module can sit tanked a week before encapsulation provides a chance for visual observation. Conversely, remote leak checks at the site in Scheme No. 7 could fail to detect a leak.

2. OF_2 reactions are also double checked by tanking at the ESF and sloshing during caravan transport. A penalty must be charged against Scheme No. 4 for the extra disconnects at the MST base which double the chance of contamination. System No. 7 remains connected until launch minimizing introduction of contaminants. The others all involve two loading or draining systems and this increases chances of a reaction.

Table 9-4. Probability of Mission Success

Parameter	Ideal Rating	Loading Scheme						
		#1	2	3	4	5	6	7
1. Best possible propulsion functional and leak checks	20	15	20	20	10	10	5	5
2. Best passivation and minimum chance of contamination	10	10	7	8	3	5	5	10
3. Minimum inflight disconnects	20	20	20	0	20	12	10	0
4. Accurate propellant weighing without spacecraft instrumentation	10	10	10	10	5	5	2	0
5. Minimum risk of destroying payload, booster, site	20	15	20	20	5	10	10	10
6. Weight savings: vessels final pressurized remotely	10	0	0	5	0	0	5	10
7. Quick turnaround	10	6	8	8	0	3	5	10
	100	76	85	71	43	45	42	45

3. The number of launch and inflight disconnects can be at a minimum. The spacecraft can be sealed like Surveyor except for TCU, insulation purge, and possible hazard sensing. The ECU or air conditioning duct to the shroud does not actually touch the spacecraft and so does not affect reliability. Conversely, additional launch disconnects and the companion inflight disconnects decrease mission reliability by increasing chance of leaks and an uneven disconnect. Emergency drain provisions can be installed manually through the access door until T-8 hours.

4. Propellant weight is more accurately determined, as has been done in the past, by placing the module and handling fixture on weighing scales in the ESF. Loading at Complex 41 means less accuracy if a weight change in the dewars is measured, or may necessitate load cell type instrumentation on the payload adapter. Advancement of the state of the art, perhaps with nucleonic devices, may alter this situation. Scheme No. 6 is penalized due to the questionable completeness of vapor loading.

Concern has been expressed over the possibility of up to a 30-day period from encapsulation to launch with a loaded spacecraft. Past experience indicates the chance of tweaking, adjusting or rechecking the payload in spite of "hands off" policies. Classified USAF payloads have been successfully isolated from abuse; so can an expensive NASA craft.

Access doors in the standard shroud not only allow manual connections for loading, thereby minimizing inflight disconnects, but also allow inspection in the payload compartment for handling damage. However, control must be exercised over those who enter, particularly visitors, lest they do more damage poking, pulling, and "inspecting." Encapsulation, transportation, erection and mating present many hazards that may result in spacecraft damage. Tanking at Complex 41 should show up any damaged propellant system parts. Manual connection of fill and vent lines at Complex 41, inside the shroud (Schemes 4 and 5), could be cumbersome, leaving the module vulnerable to damage, but subsequent inspection through the access doors should detect any defects. Access doors may be common to all modes anyway if RTS power supplies are installed on the orbiter at T-2 days.

5. Tanking at the ESF exposes the payload, booster, and site to minimum risk. If there were a catastrophic reaction or leak it is most likely to occur during passivation or tanking. In the ESF the most that is lost is a small block building beside the propulsion module. The spare spacecraft could probably still proceed with the mission. Such a catastrophe on Complex 41 is likely to destroy about 200 million dollars worth of payload capsule, booster and parts of the site. Such a complete loss would certainly cause even the spare spacecraft to miss the launch window, postponing the mission several years. Emergency drain provisions reduce the risk of loss.

6. In general, higher safety factors are required for propellant vessels to which people are exposed after filling and pressurizing. This would normally cost a significant weight increase. We believe it is not typical that the OF_2/B_2H_6 module, used as a guideline in this study, was not affected, due to being designed for very high flight pressure variations. Therefore, credit is given to designs which can be remotely loaded and/or pressurized during terminal countdown through riseoff disconnects.

7. Since planetary missions have limited calendar launch windows, it is vital to be able to replace a faulty spacecraft quickly. Tanking at the ESF allows a spare propulsion module to be tanked while the faulty spacecraft is removed from the launch vehicle, or even to hold a tanked spare ready to go. Removing a wet spacecraft would be slower than handling a dry one, due to extra equipment in the caravan and complex safety precautions. But if there were no problem with the propellant system, we would recommend leaving it tanked. Scheme No. 7 may provide the fastest turnaround: when replacement is necessary, the spacecraft may still be dry or else it can be quickly drained through LN_2 jacket lines. Complete replacement and retanking might be done

in 24 hours if really necessary. Modes 2 and 3 are also rated high having the versatility to drain or not with a tanked spacecraft already standing by (which would require some duplicate GSE and handling gear). Table 9-5 lists the main conclusions of these remarks on mission success.

Table 9-5. Prelaunch Operations versus Mission Success

Better leak checks from longer time wet and pressurized.
Caravan dynamics increase passivation checks.
In-flight disconnects decrease reliability.
Propellant weighing more accurate in ESF.
Tankage weight savings possible with countdown loading.
First passivation and loading should not be at site.
Quick spacecraft replacement desirable.
"Tweaking" and tampering through access door must be eliminated.

9.2.2 PERSONNEL SAFETY. All seven modes of propellant loading are judged acceptably safe. Personnel safety is better assured by tanking at the pad, as near launch time as possible. Reviewing Table 9-6:

1. Provisions for emergency drain and/or vent are considered essential. In Section 9.1, it is recommended that drain be initiated whenever a leak is detected because it may quickly become larger leading to a reaction, fire, or explosion. A large penalty is therefore charged against Schemes 1 and 4, which have no emergency drain. There is a compromise between speed and distance of drain. Systems 2 and 6 drain away from the problem to the base of the tower which may be slow to start due to vapor-lock. Systems 3 and 5 have catch dewars just 20 feet away in the umbilical tower where they also would be endangered by a large fire. Only System 7, with LN_2-jacketed lines, can quickly drain at any time.

2. Moving around the loaded propulsion module or loaded supply dewars involves some risk that an accident will cause a toxic release. Handling a wet spacecraft in the propellant laboratory, then the assembly building, then encapsulating in the terminal sterilization building, moving out to the side and hoisting 136 feet in the air all involve risks. Moving dewars up the freight elevator (Scheme 4) or hoisting them into the umbilical tower (Scheme 5) also increases the hazards to personnel.

3. The longer the vehicle and GSE systems are wet, the higher the chance of many types of mishaps such as leaks, shaking loose, contamination, etc.

Table 9-6. Safety Comparison

	Ideal Rating	Loading Scheme						
		1	2	3	4	5	6	7
1. Emergency safeguards: drain and/or vent away from spacecraft	20	5	15	15	5	12	14	20
2. Minimum handling of wet spacecraft and dewars	15	3	0	0	5	5	12	15
3. Minimum time spacecraft and GSE wet: less time for leak, etc.	20	4	0	0	12	12	12	20
4. Simples system operated by best trained personnel to minimize operator error	10	10	8	7	8	7	6	5
5. Loading performed remote from routine Cape activities	10	4	4	4	8	8	8	10
6. Minimum number GSE joints: minimum potential leaks, joints visible to check	10	10	6	6	8	8	7	2
7. Minimum break into systems: least change of contamination	10	8	7	6	4	4	7	10
8. Unclutter work decks and areas	5	5	4	2	2	0	4	5
	100	49	44	40	52	56	70	87

Note, however, that the spacecraft tanks are actually designed to higher pressure (400) than the GSE. But heavy ground valves, such as Annins, must generally be regarded as safer than small, light spacecraft solenoids. Handling the wet spacecraft will be a slow, methodical process. This risk can be minimized using LN_2 temperature propellant thermal control which makes the vapor pressure very low.

4. The propellant loading in the ESF-PL has some advantages also: The ESF-PL facility is basically designed for toxic propellant loading. ESF personnel, trained to work with tanked spacecraft, are basically propulsion-system-oriented specialists in structural, pneumatic, pyrotechnic, mechanical,

and propellant areas. At the pad are all types (guidance, payload, TLM, etc.) including many visitors. They can cause problems if the spacecraft is not electrically and mechanically isolated. Leaks can be observed before encapsulation. Scheme No. 7 is rated lowest due to its long coaxial lines.

5. Loading at Complex 41 is safer since it is more remote from routine Cape activities than is the ESF. Scheme 7 is best in this respect because it is only loaded during countdown when the area is intentionally evacuated for 2 miles.

6. The fewer propellant system GSE, the less chance of toxic leaks and failures. Even drain systems never used in an emergency present hazards when passivated.

7. Schemes 4 and 5 are penalized because connecting and disconnecting propellant lines can allow contamination to enter the systems, causing a reaction.

8. Schemes 3, 4 and 5 introduce safety hazards in the form of crowded work decks near the vehicle where personnel may be injured.

In conclusion, System 7, loading at Complex 41 from permanent, LN_2-jacketed propellant systems, is the safest.

9.2.3 COST ESTIMATES. Space storable propulsion module type missions will be only a portion of the Complex 41 launches. One or two pairs per year is a reasonable rate. Therefore, temporary/removable/or mobile GSE would be acceptable and leave the site less cluttered with special equipment. The cost of the GSE, while only a tiny fraction of the payload costs, still should be kept low. But costs are clearly secondary to mission success and safety. Ten basic cost elements have been considered with very rough order of magnitude dollar values applied:

	Cost (thousands of $)
1. B_2H_6 Container	
a. The mobile B_2H_6 dewar with 800-pound capacity, 100 psi operating pressure, triple wall. Design, development, procurement of three units, and proof and road testing of one unit.	200
b. Simplified LN_2 vacuum jacketed emergency catch tank.	100
c. Fixed storage tank at 2 x capacity, LN_2 jacketed	150

	Cost (thousands of $)
2. OF_2 Container	
a. Leasing an existing Allied LF_2 trailer (per phone conversation 1/13/70 with Joe Smith, Allied Chemical).	25/yr
b. New mobile dewar, like 1a.	200
c. Simplified LN_2 jacketed emergency catch tank.	100
d. Fixed storage tank, 5,000 pound capacity, 150 psi	200
3. Propellant Fill and Drain Lines	
a. Short, for LN_2 test only at ESF.	50
b. Short (10 to 50 feet at ESF or Complex 41 Umbilical Tower) bare or foam insulated, including LN_2 connections, evacuation system, flex provisions, valving and manual connection to propulsion module. Design, development, proof testing and spares of critical parts, plus site installation. Include coordination of spacecraft, shroud, site.	80
c. Long (150 feet to base of umbilical tower): otherwise the same as above. Can use same components as short system when both required. For System 6, will have vapor condenser next to spacecraft and vaporizers at dewar.	100
d. Long (500 feet) coaxial, LN_2 cooled vacuum jacketed. More site coordination installation and checkout time.	200
4. TCU (Thermal Control Unit for Spacecraft Propellants)	
a. LN_2/CF_4 vacuum jacketed dewar with spacecraft 7 day holding capability. 150°R to 300°R control range. Design, develop, fabricate two, proof install and checkout.	75
b. If mobile, two including road tests.	100
5. VDU (Vapor Disposal Unit)	
Pairs of units: for OF_2, 100 gallons 10 percent lime solution bath with recirculation pump, spray nozzles, vent burner. Design, develop, proof test, procure one. For B_2H_6, separate propane burner system, with after-scrubber.	25

	Cost (thousands of $)
6. Insulation Purge	
GN_2 and/or He reservoir plus controlled flow rate to propellant module insulation. Coordination with spacecraft including assistance on propellant module insulation development testing.	20
7. Spacecraft ECU (Environmental Control Unit)	200
Fixed 1000 cfm very dry air or GN_2 at 60 to 90°F. Design, develop, proof test, install at Complex 41 with about 180 feet insulated 8-foot ducting. (May be able to use Viking unit.) (Note: KECO unit for Surveyor = $100K procurement.) Coordination requirements and interfaces with Centaur, shroud, and payload personnel. For transporting encapsulated spacecraft a mobile purge is provided.	
8. PCU (Pressure Control Unit)	
a. Control helium loading at 3000 to 6000 psi, 150 to 500°R. Regulate and relieve propellant tank pressure from vacuum to 240 psi. Distribution and interconnection with facility. Design, develop, procure two, proof test. (Note: Feedback Systems Inc. unit for Centaur ≃ $50K procurement.)	125
b. Partial control unit for LN_2 testing only.	50
9. Hazard Sensor System	
Assume feasibility demonstrated. Probably a pair of sensors, one for each type propellant, plus multi-inlet vacuum sensing leads will be required; perhaps a group of individual detector probes. Design, development, demonstration testing, installation, calibration, etc.	25
10. Launch Disconnects	
Design of umbilical boom installation with lanyards if required. Development, procurement, installation, checkout, coordination with site, shroud, and spacecraft people.	15/disconnect

The above items, totaling about one million dollars, are not the entire OSE and facility cost. Omitted are changes required in the ESF-PL air conditioning, flooring, and paving. Some loading schemes necessitate reinforcing the twelfth level of the umbilical tower. The comprehensive training and procedure development program itself will be costly. We have not tried to estimate the cost of time delays due to weather restrictions or work stoppage to clear the area for loading and checkouts. Control of access to a loaded spacecraft will limit the free flow of people. It appears that these costs tend to average out for the seven modes being discussed. Two contingency costs which have not been included are for replacing a faulty spacecraft with a backup or potential losses of the spacecraft, launch vehicle, or even the site in event of a catastrophe. Table 9-7 summarizes all of the costs. Table 9-8 gives an overall comparison.

9.2.4 OVERALL COMPARISON. The judgment that mission success is twice as important as personnel safety (as long as the risk is acceptable in all cases) is certainly controversial. From a safety viewpoint, all modes are feasible and within KSC/AFETR safety requirements. Scheme No. 7, tanking during the launch countdown, involved the least risk.

We recommend propellant loading Scheme No. 2, tanking at ESF, plus provisions for emergency drain at Complex 41 up to T-4 hours by connecting a drain through the access door in the shroud.

Table 9-7. Rough GSE Cost Comparison

GSE Systems	Area $K	Loading Scheme 1	2	3	4	5	6	7
1. B_2H_6 Container								
a. Mobile Dewar	200	1	1	1	1	1	1	
b. Emergency Catch	100			1				
c. Fixed Dewar	150							1
2. OF_2 Container								
a. Lease Allied Trailer	25	1	1	1			1	
b. Mobile Dewar	200				1	1		
c. Emergency Catch	100			1				
d. Fixed Dewar, 150 psi	200							1
3. Fill & Drain System								
a. Short, LN_2 Only	50				1	1	1	1
b. Short	80	1	1	2@120	1	1		
c. Long	Var.		1@60				1@110	
d. Coaxial, 1000 Ft.	200							1
4. TCU								
a. Fixed	75				1	1	1	1
b. Mobile	100	1	1	1				

Table 9-7. Rough GSE Cost Comparison, Contd

GSE Systems	Area $K	Loading Scheme 1	2	3	4	5	6	7
5. Vapor Disposal Systems								
Chemical OF_2 Disposal Burner/Scrubber for B_2H_6	25	1	2	2	1	1	1	1
6. Insulation Purge	20	3	3	3	2	2	2	2
7. ECU								
Fixed & Mobile Purge	200	1	1	1	1	1	1	1
8. PCU								
a. Full System	125	1	2@175	2@175	1	1	1	1
b. Test Only	50				1	1	1	1
9. Hazard Sensor Systems	25	3	5	5	1	2	2	3
10. Launch Disconnect	15	3	4	9	3	5	6	9
Total Estimate, Million Dollars		0.935	1.135	1.390	1.115	1.170	1.040	1.325
Rating (100 = Cheapest)		100	80	55	80	75	90	60

Table 9-8. Overall Comparisons

	Ideal Rating	ESF Schemes 1	2	3	Complex 41 Schemes 4	5	6	7
Mission Success 2 × Table 9-4	*200*	*152*	*170*	*142*	*86*	*90*	*90*	*90*
Safety Table 9-6	*100*	*49*	*44*	*40*	*52*	*56*	*70*	*87*
Cost 1/2 Table 9-7	*50*	*50*	*40*	*27*	*40*	*37*	*45*	*30*
TOTAL	*350*	*251*	*254*	*209*	*178*	*183*	*205*	*207*
Rank		*2nd*	*1st*					*3rd*

10

CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

Space storable propellants, including OF_2 and B_2H_6, can be safely handled at KSC/AFETR, loaded in a moderate size propulsion module, and launched. The program office can choose from a range of propellant loading schemes from tanking more than 30 days before launch at the ESF, to loading during the launch countdown, any one of which can be safely performed. Tables 10-1 and 10-2 list new ground and vehicle requirements. Table 10-3 lists some of the basis safety points discussed earlier. The following specific points have been concluded in the study.

10.1.1 BETTER FUNCTIONAL AND LEAK CHECKS IN ESF. Tanking more than thirty days before launch provides excellent opportunities for propulsion passivation, functional and leak checks. This is basically due to the longer duration of the test period, plus accessibility, and propellant sloshing in wet spacecraft during the move to the launch pad.

10.1.2 PROPELLANT FLOW IS GREATEST HAZARD. The period of greatest hazard is during passivation, propellant transfer, and pressurization. Once these dynamic conditions cease, the risk decreases progressively with time as the system rests statically. Therefore, a basic policy should be: minimum propellant transfer activity for minimum risk. When there is no problem with the propellant system, leave it alone.

One ramification of this philosophy would be to handle the spacecraft wet, such as demating and returning it wet to the ESF to ride out a hurricane.

10.1.3 MINIMUM PERSONNEL HAZARD. There is clearly less hazard to personnel from loading during countdown, as is currently done with Centaur, than from loading in the ESF. During tanking, all personnel would be cleared back to the VIB and Saturn Complex 39 evacuated. Thus, there is obviously minimum exposure of personnel to a module loaded with toxic propellants.

10.1.4 MINIMUM OPERATIONAL RESTRICTIONS. Passivation and loading can be safely done at the ESF with roads blocked about one mile around the PL, unstable atmosphere such as usually occurs in the morning, and wind from SW or NE. Twenty-four to 48 hours after remote loading without a problem, Pad Safety could authorize limited access directly to the propulsion module for subsequent checks and assembly.

Table 10-1. New and/or Unique Requirements, OSE, and Facilities

A. *MAJOR OSE ITEMS:*

- *B_2H_6 container, 800-pound, mobile.*
- *OF_2 container, rent 5000-pound Allied trailer.*
- *Fill and drain system with purge and passivation provisions.*
- *Propellant thermal control unit (TCU).*
- *Toxic vapor disposed system (VDU).*
- *Propulsion module insulation purge.*
- *Spacecraft environmental control unit (ECU) (may use Viking's).*
- *Pressurization control unit (PCU).*
- *Hazard sensing systems.*
- *Launch disconnect umbilicals.*
- *Fluorine-resistant SCAPE suits and splash clothing.*
- *Special propellant loading training article.*

B. *EXPLOSIVE SAFE FACILITY – PROPELLANT LAB*

- *Modified air conditioning system, with discharge to VDU.*
- *New floor CRES covering compatible with propellants.*
- *Adjacent parking area for standby of propellant containers.*
- *Enlarged parking area for mobile OSE with blast wall.*
- *Meteorological monitoring system for operational restrictions.*

C. *EXPLOSIVE SAFE FACILITY – ASSEMBLY BUILDING AND TERMINAL STERILIZATION BUILDING*

- *Mobile propellant thermal control unit.*
- *Emergency drain provisions available for manual connection.*

D. *COMPLEX 41*

- *Adjacent parking area for standby of propellant containers.*
- *Special fire-fighting systems and procedures.*
- *Spacecraft weight/balance system, for on-pad loading.*
- *Propellant loading and/or draining systems.*
- *Pressurization and venting systems.*

Table 10-2. New Spacecraft Requirements

- *Absolutely leak tight valves, seals, disconnects.*
- *Hazard-sensing inside insulation shroud.*
- *Insulation system compatibility with propellant vapors.*
- *Propellant system arranged for purge, evacuation, passivation.*
- *Launch disconnects.*
- *Emergency drain provisions available.*
- *Access door for RTG installation and propulsion servicing.*
- *Post-tanking leak and functional tests.*
- *Onboard propellant weighing.*
- *Integrated ground/vehicle propellant thermal control.*

Table 10-3. Safety Conclusions

- *Minimum propellant transfer = minimum risk.*
- *Emergency drain required if leaks detected.*
- *Passivating, loading, and pressurizing are the most hazardous operations.*
- *Comprehensive personnel training including a propellant module test article.*
- *Minimize joints in propellant systems to reduce leakage.*
- *A wet spacecraft can be demated and removed.*
- *TCU failure leaves 24 hours for corrective action.*
- *Use water spray or fog only on a fire.*

10.1.5 OF_2 TOXICITY LIMITS TIGHT. The allowable concentrations of OF_2 are extremely tight. The emergency exposure limit of 0.5 ppm OF_2 for 10 minutes is 30 times less than the 15 ppm allowed for pure fluorine.

10.1.6 SIMPLE OSE REQUIRED. Preliminary sketches are included for the main units of GSE required: an 800-pound diborane dewar and a thermal control unit are typical of the simple OSE required. Table 10-1 lists the major new or unique requirements of KSC/AFETR that would be necessary for prelaunch operations with a space storable propulsion module.

10.1.7 EXCELLENT TANK SAFETY. Standby of a loaded propulsion module is safer than storage in the storage container from a pressure standpoint: the ground dewar, designed to operate at 100 psi, will have a factor of safety per ASME Boiler Code of 4, or a minimum burst of 400 psi. The propulsion module tanks are designed to operate at 400 psi maximum with a safety factor of 2, so the minimum burst is 800 psi. The loaded spacecraft will be pressurized to 100 to 240 psi prior to launch. Therefore, during standby, the airborne tanks actually have a higher safety margin burst pressure than the GSE dewars. This situation may be unique to pressure-fed propulsion modules. Table 10-3 is a summary of the safety conclusions.

10.2 RECOMMENDATIONS

10.2.1 RECOMMEND ESF TANKING. To achieve maximum chance of mission success, it is recommended that the spacecraft be loaded in the Explosive Safe Facility Propellant Laboratory. Figure 10-1 shows a general arrangement of the major equipment required outside the Propellant Laboratory.

It is further recommended that the prelaunch operational flow sequence for an OF_2/B_2H_6 propulsion module, Figure 10-2, be followed. The basis for this flow chart is the latest 1975 Viking plan, including the use of three major buildings at the ESF. It is estimated that propulsion module propellant loading in the ESF-PL will require one to two weeks and should be completed more than one month before launch. After encapsulation, the spacecraft should be mated to the Titan-Centaur, about two weeks before launch. Final prelaunch servicing, pressurization, installation of the orbiter's RTG, removal of all temporary emergency drain lines, and buttoning up the access door can be done one day or less before launch. This operating sequence allows thorough propulsion functional and leak checks, after tanking, more than a month before launch and a relatively short period on the launch site for final integration with the booster and launch control equipment. We believe this sequence maximizes chances of mission success and minimizes chances of losing the payload, with acceptable risk to personnel.

10.2.2 FACILITY AND PROCEDURE VALIDATION. It is recommended that a propulsion module test and training article be used to validate the propellant loading system and procedures before a flight article is loaded, first using LN_2, then OF_2 and B_2H_6.

10.2.3 INITIAL LOADING OF FLIGHT ARTICLE. It is recommended that flight articles be passivated, loaded, and raised to operating pressure at least once before mating to the spacecraft and then to the booster. Stated another way, the greatest risk of losing the payload, booster, and much of the site — and therefore, aborting the mission — occurs from initially tanking the propulsion module at Complex 41.

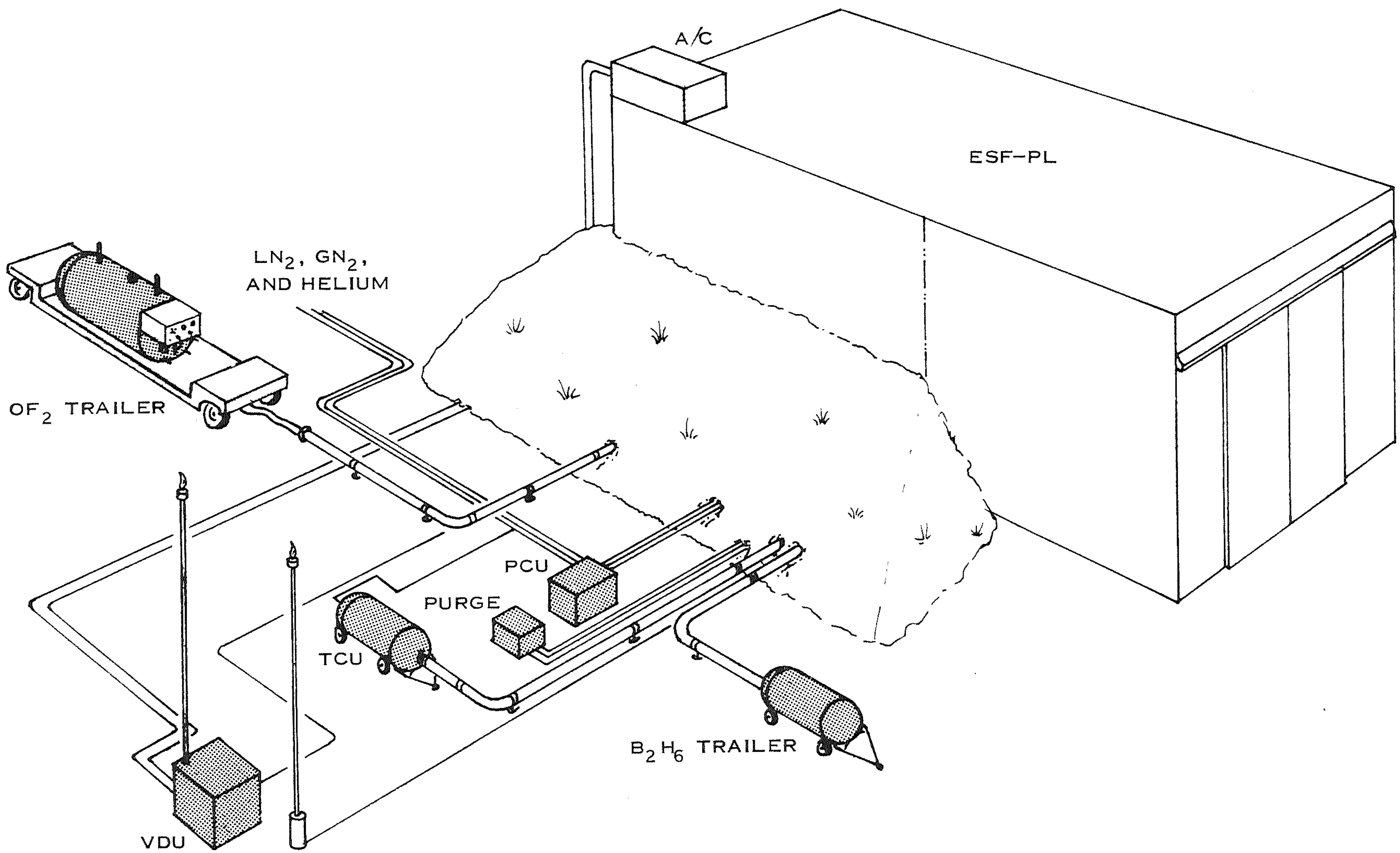


Figure 10-1. Major OSE Required at Propellant Laboratory

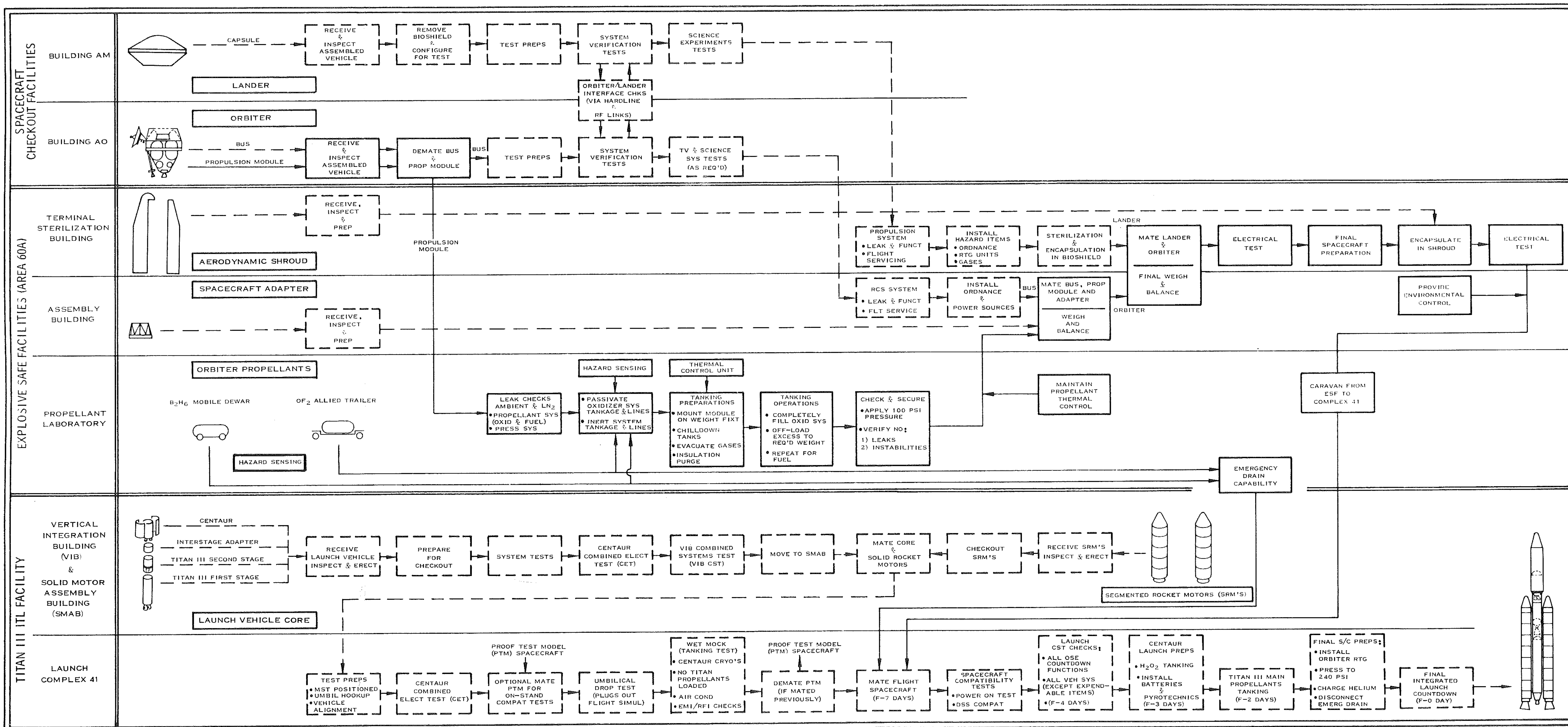


Figure 10-2. Prelaunch Operational Flow Sequence

10.2.4 MINIMUM INFLIGHT DISCONNECTS. It is recommended that spacecraft propulsion modules have few inflight disconnects for higher reliability. With space storable propellants, a minimum of three inflight disconnects is required for propellant thermal control, insulation purge, and internal hazard sensing. The environmental control (air conditioning) will add a fourth launch disconnect.

10.2.5 ACCESS DOOR. Access doors are recomended in the shroud both to install the RTG units and to service the propulsion module. Through this access, temporary flex hoses can be manually connected for a range of functions from checkouts to emergency drain.

10.2.6 HAZARD SENSING IN THE PROPULSION MODULE. We recommend that a hazard sensing line penetrate the insulation-meteorite protection shroud around the propellant tanks.

10.2.7 EMERGENCY DRAIN. It is recommended that emergency drain and vent systems be available. These provisions are to be used as a safeguard against catastrophe. Detection of a leak, which could swiftly lead to a reaction or fire, should trigger emergency draining.

10.3 SUGGESTED FOLLOW-ON TASKS

This study has touched on a broad range of subjects to show that prelaunch operations are feasible with a space storable propulsion module. There are several facets of this study which deserve a deeper look.

Optimization of a Vapor Disposal Unit (VDU) would allow fabrication for use on current technology programs at JPL, AFRPL, LeRC, Rocketdyne, etc. As the propulsion module characteristics become bracketed, a tradeoff study could be run to optimize the integrated airborne and ground Thermal Control System. Due to its extremely critical nature, a comprehensive propulsion system checkout should be evaluated for several alternative systems designs such as pump feed versus pressurized (and, therefore, thin wall tanks versus those capable of withstanding a vacuum), diaphragm versus capillary propellant orientation, pyrotechnic versus solenoid valves. The differences caused by FLOX/methane (probably in a larger, pump-fed module) should be defined in depth.

There are also some specialized problems which deserve further attention.

10.3.1 TOXICITY STUDIES. Toxicity studies and tests should be designed to generate better data and increased experience with OF_2, other fluorine compounds, and B_2H_6. In particular, it is hoped that the short-term exposure values, EEL's, for OF_2 can be raised an order of magnitude from the currently published 0.5 ppm for 10 minutes, which is 30 times less than allowed for F_2 and 14 times less than for ClF_3 (see details in Section 2.2.5).

10.3.2 SENSOR DEVELOPMENT. Hazard sensing intrumentation should be developed to remotely sense as little as 0.1 ppm OF_2 and B_2H_6, selectively, under KSC/AFETR field conditions. Currently available commercial units are not selective, not sufficiently sensitive, and/or require manual operation (see details in Section 2.4.3).

10.3.3 DIFFUSION STUDIES. Diffusion studies and tests should be made to place on a firmer theoretical and experimental foundation the problem of diffusion of elevated, puff sources of cryogenic propellants. The specific characteristics of OF_2 evaporation rates, reaction with water spray, and ecological and biological effects should be evaluated (see details in Section 2.5.5).

The above three suggestions involving safety would benefit current technology and development programs and are judged mandatory before Cape operations could begin or even be firmly planned.

10.3.4 INSULATION COMPATIBILITY. Tests should be run to evaluate the compatibility of various insulation arrangements with a propellant leak. Most insulation materials such as foam, Mylar sheet, dexiglass, and nylon nets are all basically incompatible with OF_2 or any fluorine compound. But a leak trapped under tight foam would more likely react than when diluted by an inert purge in relatively free flowing superinsulation layers (discussion in Section 7.2).

10.3.5 STUDY OF DIBORANE FREEZING. An analysis should be made of the operational benefits of freezing diborane. With reasonable LN_2 cooling coils how long would formation take? (Can it be frozen fast enough to preclude the necessity for emergency drain?) How long after launch will melting be sufficient to allow for midcourse correction? How would the ice or slush interact with a capillary propellant orientation system? The real safety and performance benefits whould be assessed (see Section 3.1.3).

10.3.6 HISTORY OF PRELAUNCH PROPELLANT PROBLEMS. Statistical analysis of emergencies, incidents, leaks, and other propellant related problems encountered with the Surveyor, Mariner, Centaur, and Agena vehicles should be compiled. Emergency procedures, safety restrictions, indeed, the choice of basic modes of operations are influenced by the statistical chances of a failure. Factual data would substantiate judgments. The Titan III may provide constructive data on the probability of toxic releases, etc. To our knowledge, there have been no major accidents at KSC with liquid propellants, but there were several fatalities in 1964 when a solid ABL X248 motor ignited in an assembly room.

10.3.7 DEVELOP LEAK TIGHT VALVES. Really leak-tight valves and slip couplings are required for both ground handling and space flight. Several valve development programs sponsored by AFRPL have shown promise for large components (about two inch diameter line size). For a nominal 1000 pound thrust system, components more like 1/2 inch diameter are required. Solenoids and pyrotechnic valves are candidates (see Section 7.3).

10.3.8 STUDY WEIGHING TECHNIQUES. Techniques for weighing spacecraft should be evaluated. Mission performance degradation should be determined for a range of propellant mass inaccuracies. Direct weighing methods should be compared with other ground and airborne techniques such as flowmeters, level gages, load cell measurements, etc. The penalty for spacecraft complexity, if any, should also be assessed. An attractive idea to consider is the temporary installation of load cell/strain gage type measurements on the payload adapter, to be used during loading and removed before launch (discussed in Section 7.8).

11

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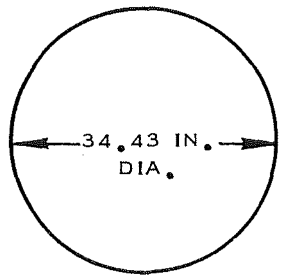
APPENDIX A

AIRBORNE TANK CONFIGURATIONS AND THERMAL DATA

A.1 AIRBORNE TANK CONFIGURATIONS, EQUAL VOLUME

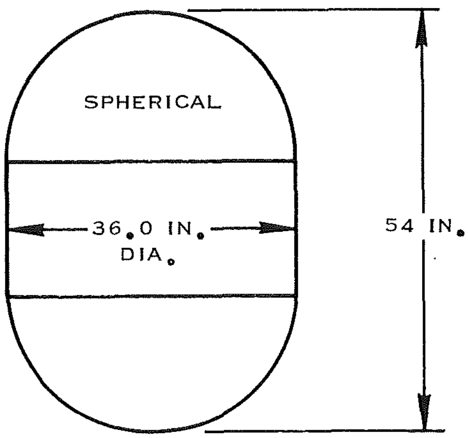


4 SPHERES

Single Tank Vol. = 12.37 cu. ft.
Surface Area = 25.86 sq. ft.

Total Vol., 4 Spheres = 49.49 cu. ft.
Total Surface Area = 103.45 sq. ft.

Total Surface Area, 2" Insulation
= 128.88 sq. ft.

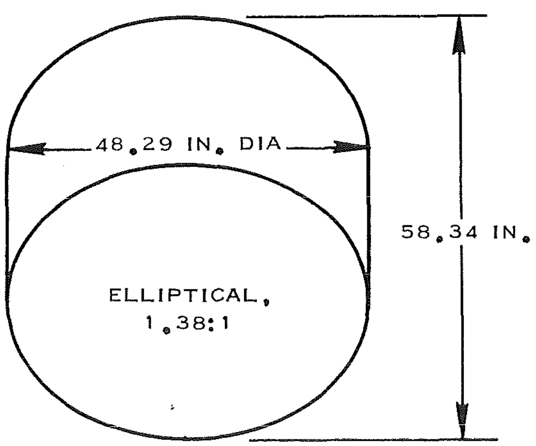


2 CYLINDERS

Single Tank Vol. = 24.74 cu. ft.
Surface Area = 42.41 sq. ft.

Total Volume = 49.48 cu. ft.
Total Surface Area = 84.82 sq. ft.

Total Surface Area, 2" Insulation
= 101.23 sq. ft.



1 COMMON BULKHEAD

Tank Volume = 49.48 cu. ft.
Surface Area = 69.00 sq. ft.

Surface Area, 2" Insulation = 79.25

A.2 LN_2 REFRIGERANT CONSUMPTION FOR AIRBORNE TANKS

Assume: Tank configurations as in Paragraph A.1.

2 inch foam insulation. $t = 2$ inches
$K = 0.020$ Btu/(hr)(ft^2)(°F/ft)

$\Delta T = 560°R - 220°R = 340°$

Heat absorption by LN_2 for heat of vaporization only, no superheat (conservative)

Effective heat transfer area $A = \sqrt{A_{tank} \cdot A_{insul}}$

$$Q = \frac{K \Delta T A}{t/12} = 40.8 \text{ A Btu/hr.}$$

Four Spheres

$A = \sqrt{(103.45)(128.88)} = 115.47$ sq. ft.

$Q = 40.8 \text{ A} = (40.8)(115.47) = 4,711$ Btu/hr

$$LN_2 \text{ EVAP/DAY} = \frac{Q}{h_{fg}}(24) \text{ lb/day} = \frac{4,711}{85.5}(24) = 1,322 \text{ lb/day}$$

Cost = 1,322 ($0.015) = $19.83/day.

Two Cylinders

$A = \sqrt{(84.82)(101.23)} = 92.66$ sq. ft.

$Q = 40.8 \text{ A} = (40.8)(92.66) = 3,780$ Btu/hr.

$$LN_2\text{/day} = \frac{Q}{h_{fg}}(24) \text{ lb/day} = \frac{3,780}{85.5}(24) = 1,061 \text{ lb/day}$$

Cost = 1,061 ($0.015) = $15.92/day.

Common Bulkhead Tank

$A = \sqrt{(69)(79.25)} = 73.95$ sq. ft.

$Q = 40.8 \text{ A} = (40.8)(73.95) = 3,017$ Btu/hr

$$LN_2\text{/day} = \frac{Q}{h_{fg}}(24) \text{ lb/day} = \frac{3,017}{85.5}(24) = 847 \text{ lb/day}$$

Cost = 847 ($0.015) = $12.70/day.

A.3 AIRBORNE TANK PRESSURE RISE, LOCKED-UP CONDITION WITH NO REFRIGERATION

Assume: Initial Tank Condition: 220°R
Final Tank Condition: 150 psig
Two cylindrical tank configuration

OF_2 Tank

1. 220°R, 9.0 psia, $h_{f_1} = -137.7$ Btu/lb
2. 305°R, 150 psig, $h_{f_2} = -114.6$ Btu/lb

$$T_{ave} = \frac{220 + 305}{2} = 262.5°$$

$$A = 92.66/2 \text{ (Paragraph A.2)} = 46.33 \text{ sq.ft.}$$

$$Q_{OF_2} = \frac{K \Delta T A}{t/12} \text{ Btu/hr.}$$

$$= \frac{(0.02)(560 - 262.5)(46.33)}{t/12}$$

$$= 1,654 \text{ Btu/hr.}$$

$$\text{Pressure Rise Time} = \frac{(h_{f_1} - h_{f_2})(W)}{Q}$$

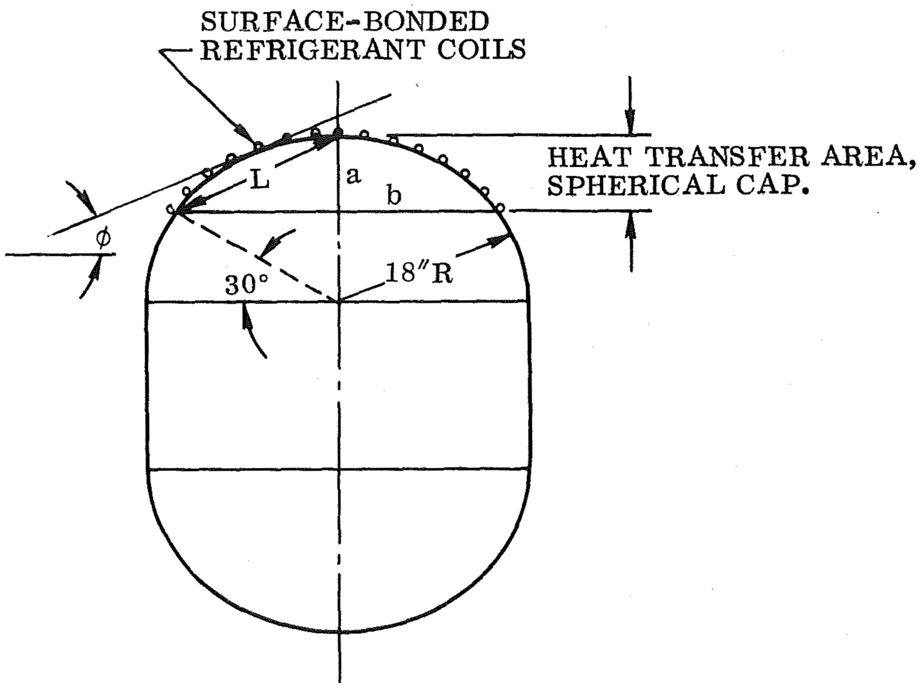
$$= \frac{(137.7 - 114.6)(1,870)}{1,654}$$

$$= 26.1 \text{ hours.}$$

NOTE: The 26 hour interval for tank pressure to rise to 150 psig assumes that the ullage vapor temperature is the same as the liquid temperature, based on near-uniform wall temperature (thick-walled vessel), slow rate of heat influx to the tank, and short heat transfer path from ullage to liquid. In an actual case, the ullage vapor temperature will be slightly higher than the liquid temperature, causing the ullage pressure to reach 150 psig in somewhat less time than indicated. The effect is dependent on final tank and insulation design, however, and in this case is considered too small to warrant further analysis based on further design assumption. Consider pressure rise time to be greater than 24 hours.

A.4 AIRBORNE TANK PROPELLANT VAPOR CONDENSATION, VAPOR TRANSFER SYSTEM

Assumed tank configuration:



$$\text{Cap Area} = \pi\,(a^2 + b^2)$$
$$= \pi\,[(0.5\,r)^2 + (0.866\,r)^2]$$
$$= 7.07 \text{ sq. ft.}$$

ϕ, inclination angle of condensing surface = 30°, nominal. (ϕ varies from 60° to 0°).

L, slant height of condensing surface = 18 inches.

Nusselt's equation for film conductance of pure saturated vapor condensing on an inclined surface:

$$h_c = 134.8 \left[\frac{k^3\, \rho^2\, h_{fg}\, (\sin \phi)}{L\, \mu\, \Delta T} \right]^{0.25} \quad \text{Btu/(hr)(ft}^2\text{)(°F)}$$

where:

k = liquid thermal conductivity, Btu/(hr)(ft^2)(°F/ft)
ρ = liquid density, lb/cu. ft.
h_{fg} = heat of vaporization at vapor saturation temperature, Btu/lb

ϕ = condensing surface angle of inclination
L = condensing surface slant height, ft.
μ = liquid absolute viscosity, lb/(ft)(hr)
ΔT = condensing temperature differential, from tank wall to vapor saturation temperature.

For OF_2

50 psig vapor transfer pressure, 271°R saturation temperature.

t_{wall} = -320°F (LN_2): 140°R

ΔT = 271° - 140° = 131°R

k = 0.1451 Btu/(hr)(ft^2)(°F/ft). (Conservative for 271°R)

(From Allied Chemical Corp., Report No. 65-62, dated 11-15-65:

k for 230°R = 0.00061 cal/(sec)(cm)(°C)

= 0.1451 Btu/(hr)(ft^2)(°F/ft)

$\rho \cong$ 90 lb/cu.ft. Conservative. Varies from 87.5 at 271°R condensation temperature, to 111.5 at 140°R wall temperature.

h_{fg} = 76 Btu/lb at 271°R

$\mu \cong$ 0.684 lb/(hr)(ft). Conservative.
(0.2826 cp at 232°R = 0.684 lb/(hr)(ft); value is lower at condensation temperature of 271°R).

$$h_c = 134.8 \left[\frac{(0.145)^3 (90)^2 (76) (0.5)}{(1.5) (0.684) (131)}\right]^{0.25}$$

$$= 219 \text{ Btu/(hr)(ft}^2\text{)(°F)}$$

$$\text{Condensation Rate} = \frac{h_c A \Delta T}{h_{fg}}$$

$$= \frac{(219)(7.07 \text{ sq.ft.})(131)}{76}$$

$$= 2,670 \text{ lb/hr}$$

$$\text{Load Time} = \frac{\text{Propellant load}}{\text{Condensation Rate}} \times 60$$

$$= \frac{1,870 \text{ lb}}{2,670 \text{ lb/hr}} \times 60 = \underline{\underline{42 \text{ minutes}}}$$

For B_2H_6

15 psig vapor transfer pressure, 351°R saturation temperature.

t_{wall} = 220°R

ΔT = 351° - 220° = 131°R.

k = 0.0555 Btu/(hr)(ft^2)(°F/ft)

ρ ≅ 25.8 lb/cu. ft. (at 351°R)

h_{fg} = 224.3 Btu/lb

μ = 0.2628 lb/(hr)(ft) at 351°R.

$$h_c = 134.8 \left[\frac{(0.0555)^3\ (25.8)^2\ (224.3)\ (0.5)}{(1.5)(0.2628)(131)}\right]^{0.25}$$

= 95 Btu/(hr)(ft^2)(°F)

$$\text{Condensation rate} = \frac{h_c\ A\ \Delta T}{h_{fg}}$$

$$= \frac{(95)\ (7.07)(131)}{224.3}$$

= 392.3 lb/hr.

$$\text{Load time} = \frac{\text{Propellant load} \times 60}{\text{Condensation rate}}$$

$$= \frac{625 \text{ lb}}{392.3 \text{ lb/hr}} \times 60$$

= 95.6 minutes.

APPENDIX B

THERMAL PROPERTIES

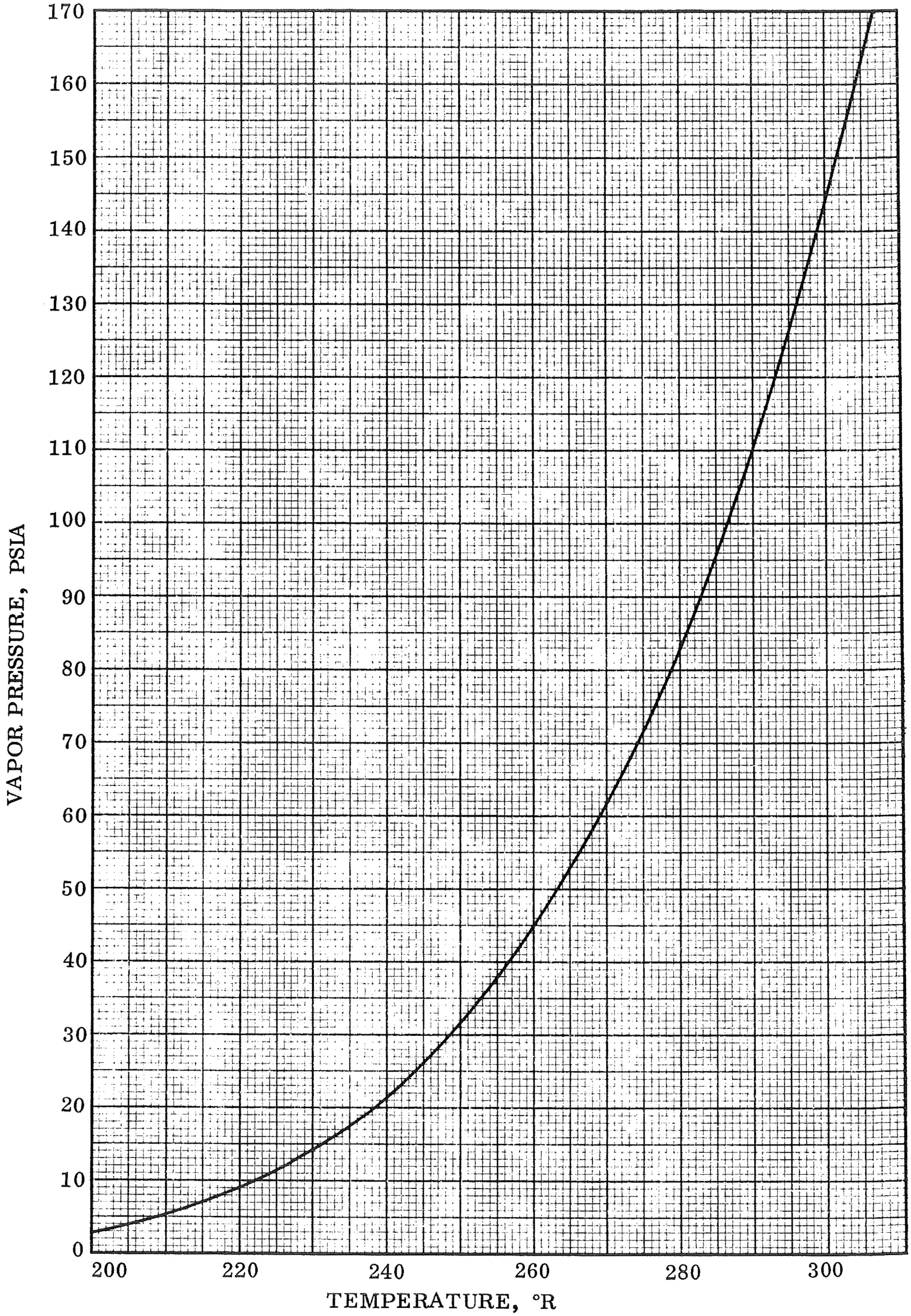


Figure B-1. Oxygen Difluoride (OF_2) Vapor Pressure

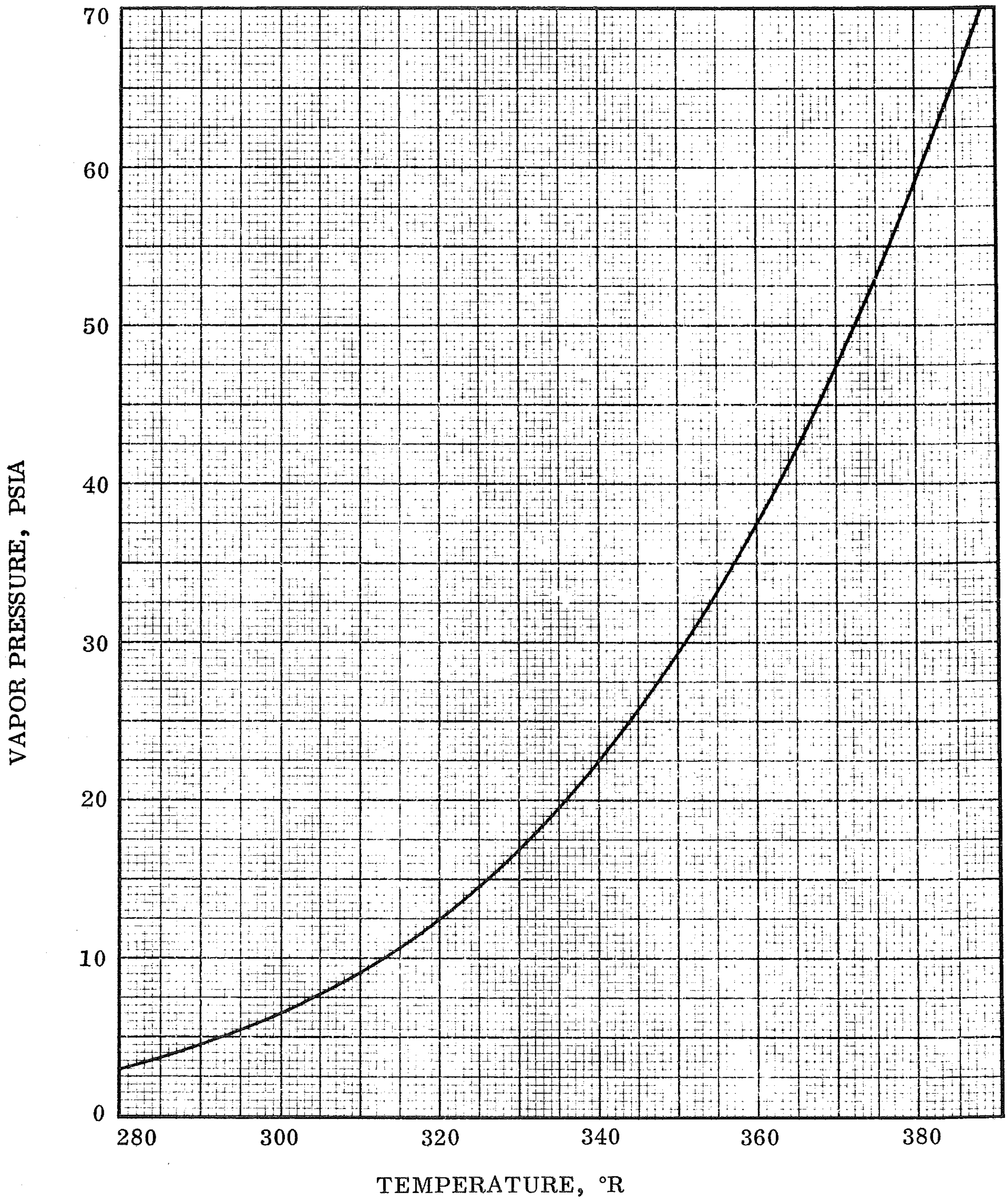


Figure B-2. Diborane (B_2H_6) Vapor Pressure

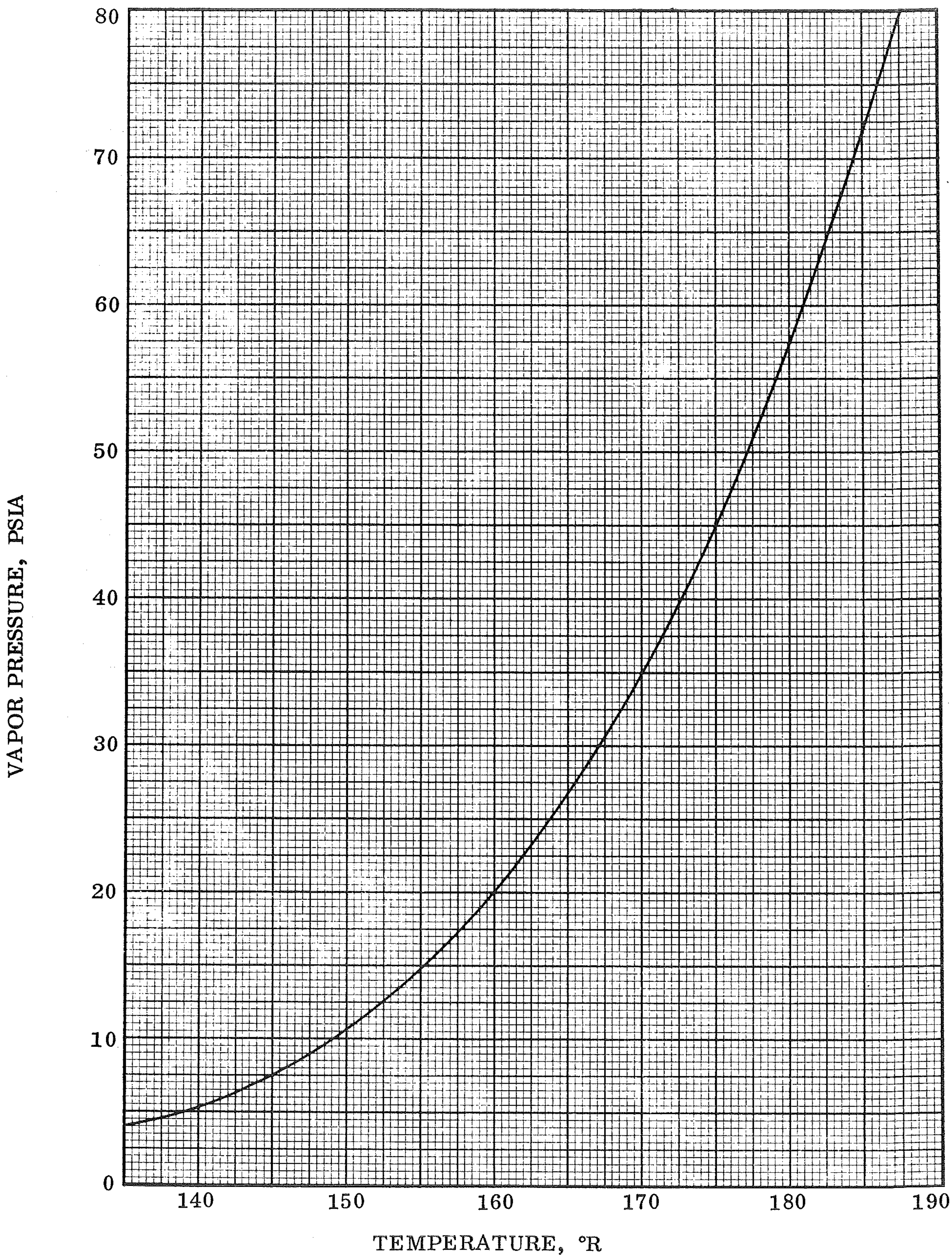


Figure B-3. 82.5 Percent FLOX Vapor Pressure

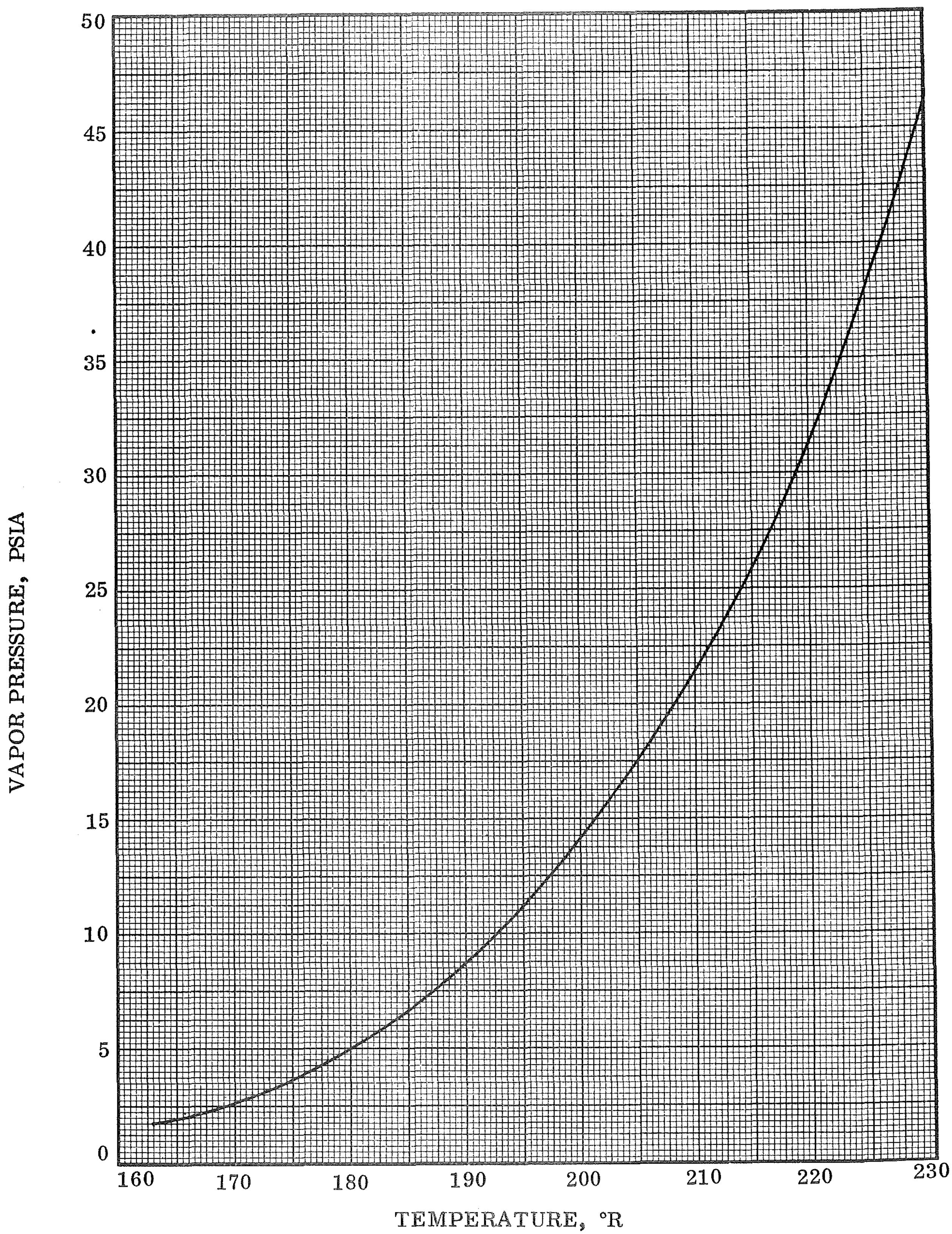


Figure B-4. Methane (CH_4) Vapor Pressure

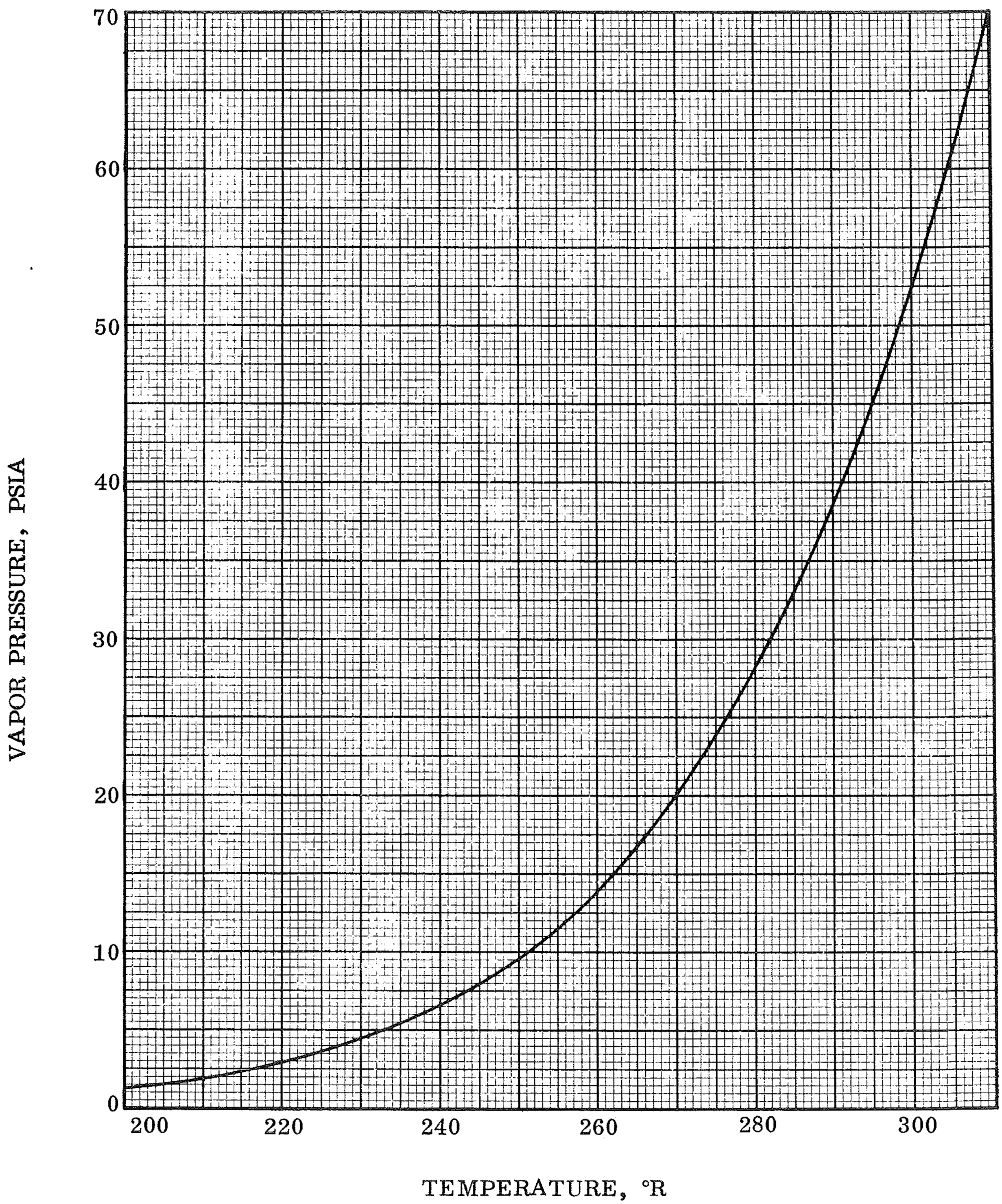


Figure B-5. Freon 14 (Tetrafluoromethane) Vapor Pressure

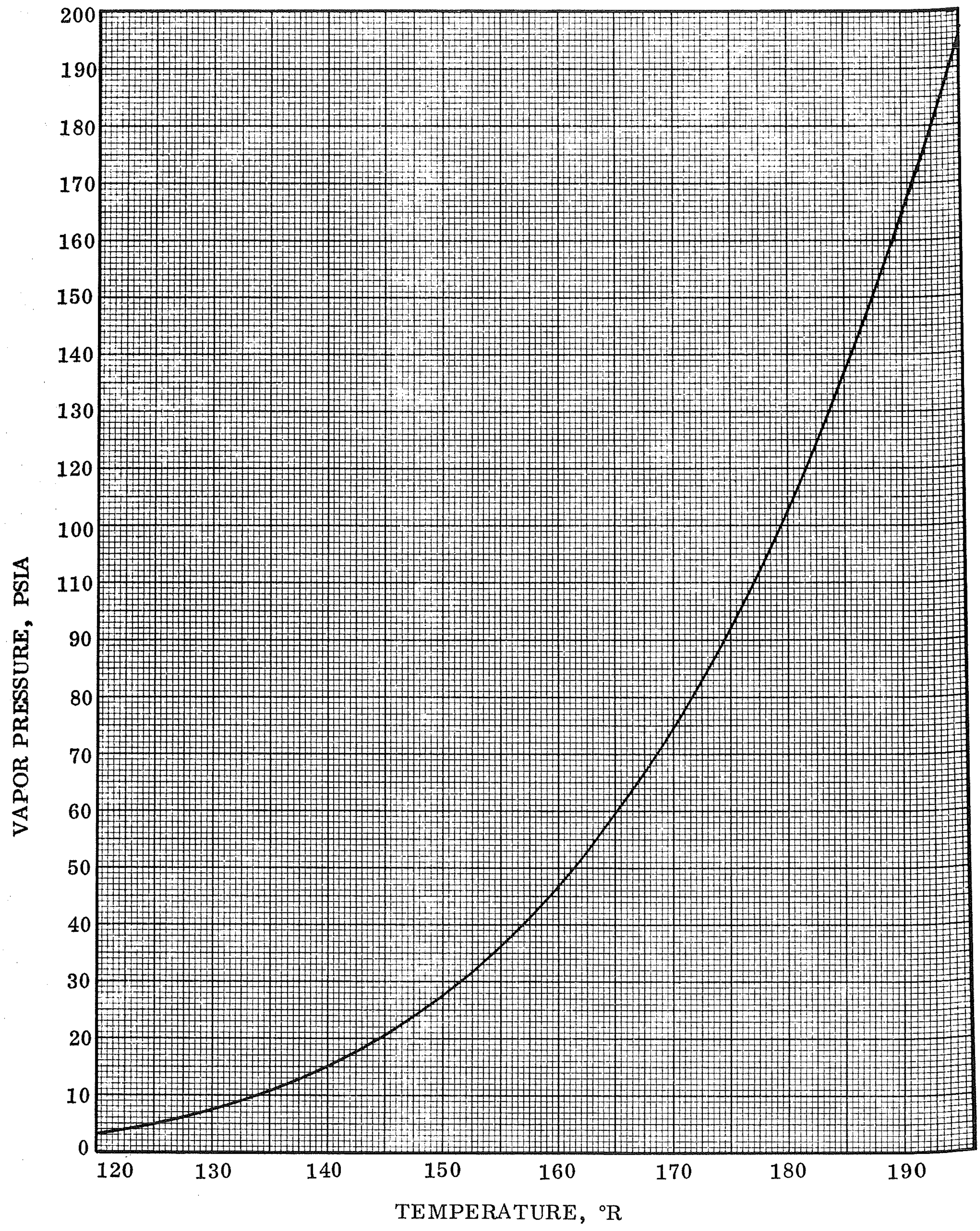


Figure B-6. Nitrogen Vapor Pressure

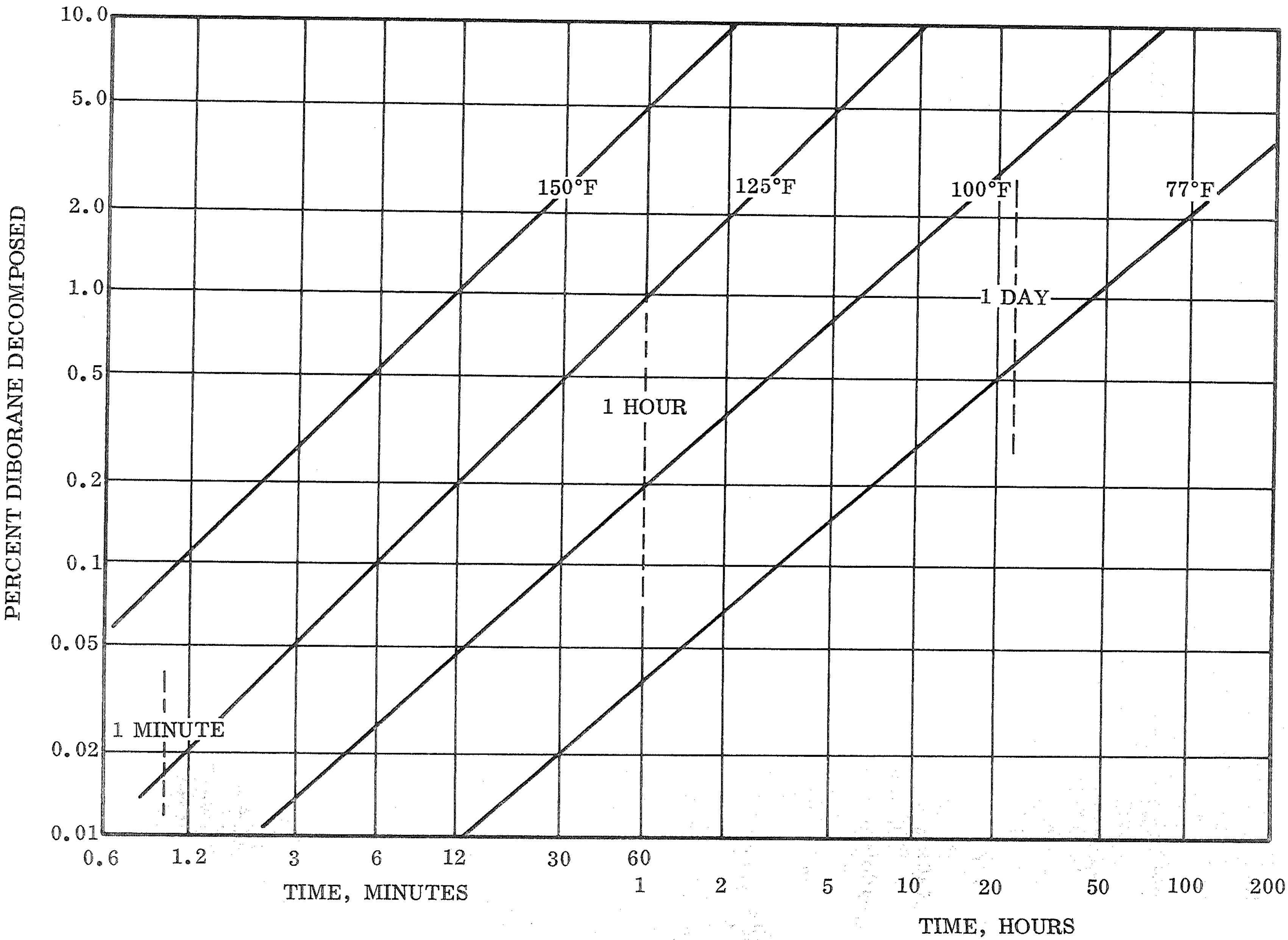


Figure B-7. Diborane Decomposition

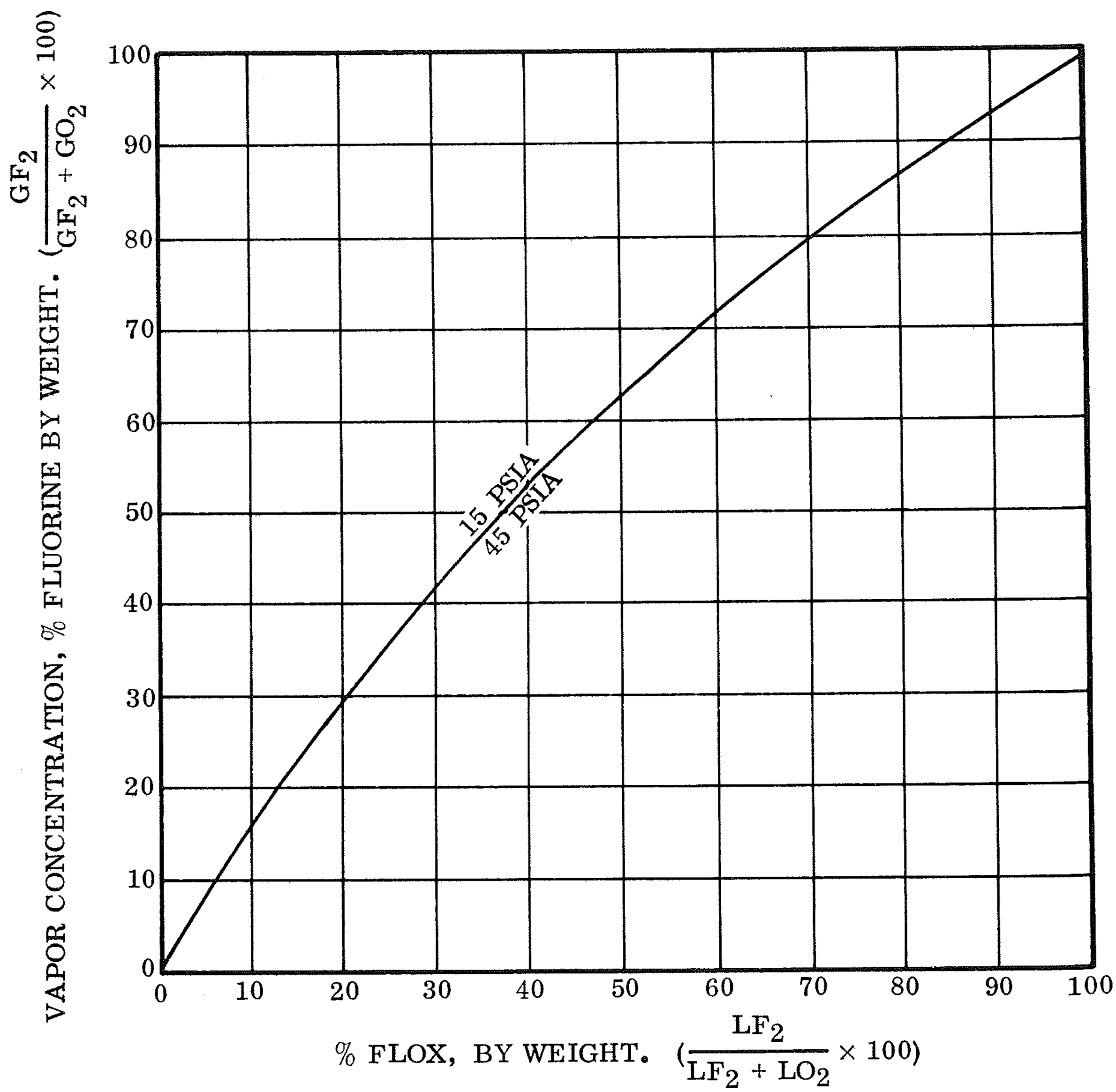


Figure B-8. FLOX Vapor Concentration

APPENDIX C

NAS7-742 INTERIM BRIEFING ATTENDANCE LIST

22 October 1969, KSC/ETR Hanger H, 9:00 AM - 5:00 PM

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Jack Suddreth	NASA/Hq.	Code RPL	202-962-1704
Donald L. Young	NASA/JPL	Liq. Prop. S.S. Mod.	213-354-3217
Wayne A. Thomas	NASA/LeRC	CRD	216-433-6116
Bernard I. Sather	NASA/LeRC	CRD	216-433-6225
Rocco A. Sannicandro	NASA-KSC	FSO	305-867-3472
George R. Berry	Lt. Col. USAF	ETR/ETDM	305-494-2114
John Willard	Capt. USAF	ETR/ETDM	305-494-4330
Louis J. Ullian	Hq. AFETR	ETDM/Miss. Safe.	305-494-4330
Russell R. Rudolph	Capt. USAF	ETR/ETX	305-494-2762
F. A. Thayer	TIII USAF	Safety/DWBT/ATW	305-853-9197
R. O. Cooper	TIII USAF	Safety/DWBT/ATW	305-853-9197
R. E. Highley	PAA	Pad Safety	305-853-5827
H. P. Wagner	PAA	Pad Safety	305-853-5827
Lewis H. Stone	PAA	Pad Safety	305-853-6891
Ramon P. Cesta	PAA	Env. Health	305-853-3281
Henry N. Levy, Jr.	JPL/ETR	ESF Mgr.	305-853-2161
Les C. King	GDC-ETR	Safety	305-853-5885
Barry J. Waldman	Rocketdyne	Project Engineer	213-884-2644
Glenn G. Baxter	GDC/ETR	Cape Operations	305-853-6331
Sam Kaye	GDC/SD	Prop. Chemistry	714-277-8900, x3119
Daniel A. Heald	GDC/SD	Predesign	714-277-8900, x1219

ADDITIONAL PERSONS CONTACTED ON PROPELLANT HANDLING

NAME	PHONE	ORGANIZATION	FUNCTION	TOPIC
A. J. Toering	412-538-3510	Callery Chem	Mgr. of Sales	Propellants Instruments
Capt. Bob Smith	1-553-2101 -2521	EAFB RPPOF	RPPOF	Meteorology
Jim Dicke	919-549-8221 x544	H.E.W. N.A.P.C.A. Essa	Chief, Air Qual. M'gmt. Sect	Atmospheric Dispersion
Dr. Duane Haugen	617-274-6100	AFCRL (Cambridge, Mass)		Ocean Breeze

NAME	PHONE	ORGANIZATION	FUNCTION	TOPIC
Jim R. Smith	213-648-6321 -5000	Aerospace Res. Corp.		Ocean Breeze Dry Gulch
Ernest Levens	213-399-9311	Douglas Corp.	Corp. Dir. of Safety	SCAPE Suit
Ken Regier	213-679-8711 x232	TRW, Redondo	Safety Engr.	SCAPE Suit
Leo A. Spano	617-653-1000 x2484	Natick Army Lab.	AMXRE-CCE	SCAPE Suit
John Rozas	213-884-2273,4	Rocketdyne	Safety Engr.	SCAPE Suit
Les King	305-853-5885	GDC	Safety	ETR Operations
Lou Ullian	305-494-2487	USAF/PAFB	Ordinance	Missile Safety

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Robert S. Levine	NASA HQ/RPL	202-962-1703
James H. Kelley	JPL	213-354-3941
T. L. Nielsen	JPL	ETS 7428
Donald L. Young	JPL	213-354-3217
Robert Lem	JPL	213-354-5360
R. W. Riebling	JPL	
Walter B. Powell	JPL	213-354-3554
A. Nash Williams	JPL	213-354-2047
Charles R. Foster	JPL	
G. Yankura	JPL	213-354-6537
R. H. Warren	JPL	213-354-5689
L. F. Massimind	JPL	213-380-2083
J. W. Behm	JPL	213-354-3159
W. H. Tyler	JPL	213-354-7190
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Jack H. Rupe	JPL 384	213-354-3556
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Gerry Sayles	AFRPL	714-553-2340
Robert L. Wiswell	AFRPL	714-553-2730
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Dan A. Heald	GDC	714-277-8900, 1219
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